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The Mechanical and Chemical Properties of the HY 100 Pressure Hulls of the Submarine, ALVIN

by

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APPROVED FOR DISTRIBUTION Paul M. Fye

Paul M. Fye, Director

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Abstract

This report presents mechanical and chemical test data from the three pressure hulls fabricated for the Deep Research Submarine, ALVIN. The data is discussed briefly, the low Charpy V-Notch values after stress relief noted, and recommendations made for further testing required for design and evaluation. The three hulls are compared with reference to failure criteria.

Introduction

The information contained herein was compiled during the calendar year 1963 concurrent with the design and fibrication of the submarine ALVIN. Some of the information was required by the specifications, Ref. 19 and 20. Some was not. The principal sources are as follows:

1) Lukens Steel Co., Coatesville, Pa.
2) Hahn and Clay, Houston, Texas
3) Southwestern Lab., Houston, Texas
4) Isaacson Iron Works, Seattle, Wash.
5) McKay Co., Pittsburgh, Pa.
6) Cook Heat Treating Co., Houston, Texas
7) General Welding Co., Houston, Texas
8) U.S. Navy Inspector, Houston, Texas
9) WHOI Resident and Field Inspectors
10) David Taylor Model Basin

A substantial amount of specimen stock from the ALVIN hulls was sent to the David Taylor Model Basin, Naval Research Laboratory, U.S. Navy Materials Laboratory, NYNS, and WHOI for analysis. The data included in this report was used by the above activities in establishing test programs making use of the ALVIN material. As discussed in section 2B, the hulls have less fracture toughness than was anticipated early in the design stage, but preliminary results from testing at NRL indicate satisfactory drop weight tear energy.

The information in this report is limited to mechanical and chemical properties. It is planned to report the detailed fabrication chronology including quality assurance and evaluation inspection separately. This information is, of course, vital to a meaningful interpretation of the material included in this report.

1. Chemical Analysis

Chemical analyses, all from test drilling chips except for Lukens heat B0091 which is a ladle analysis, are reported in Table 5. A check analysis was made from window insert drops from each of the hemispheres before stress relief. It is noted that the reported molybdenum content increased from 0.60% to values up to 0.69%. Unfortunately no check analysis of the Lukens plate was made so that the original value of 0.60% is suspect. The maximum value permitted by MIL-16216 (SHIPS) on check analysis is 0.63%.

2. Mechanical Properties

A. Tension and Compression Properties are reported in Table 6 with load-deflection curves from tensile and compressive tests presented in Fig. 10-1 through 10-28. The curves are presented as reproductions of the original records and have not been reduced to stress vs. strain. Fig. 11 indicates a typical relationship between tensile and compressive data. The substantial difference in proportional limit makes possible an increase in anticipated collapse depth above the preliminary design value. Fig. 12 indicates some increase of static strength as a result of stress relief. The difference in edge vs. drop data is consistent with the greater working near the hemisphere rim.

B. Charpy V-notch data is presented in Table 6 and in Fig. 4, 5, 6, and 7. There is clearly a large gap between the properties of the stress relieved hemispheres and the plate of Ref. 12 and 13. Fig. 7 shows the ALVIN stress relieved and not stress relieved data superimposed on MATLAB curves of Ref. 12 and 13. The NDT for the material of Ref. 12 was -190°F. The V-notch Charpy transition curve from a proprietary steel (Ref.15) is also shown with a correlated NDT of -70±F. from drop weight tear tests.

Realizing that any extrapolation of toughness data can be made only with great care, it appears, nevertheless, that the NDT of the ALVIN spheres may be in the neighborhood of 0°F. It has been recommended that "Accident case loading" as defined in Ref. 15 be allowed only above NDT +60°F. It is noted that the Charpy-temperature curve of the heat affected zone of an HY100 weld (Fig.11 Ref.25) is above that of ALVIN as stress relieved.

It is fortunate that a considerable amount of stock from the ALVIN hulls is available for test.

3.0 Weld Procedure and Welder Qualification

3.1 Electrode

The welding electrodes were manufactured by the McKay Co. of Pittsburg , Pa. to meet the requirements of Specification MIL-E-22200/1B(SHIPS), type MIL-11018. The chemical analysis data is presented in table (5). Tensile and Charpy V-notch test data per Fig. 3, MIL-F-22200/1B, was as follows:

	Y.S.(psi)	U.S.(psi)	% Elong. in 2"	Charpy V-notch -60°F. ft.lbs.
As Welded	106,000	118,000	27	45.2
Stress Relieved	98,375	110,500	24	32.8
As Welded	98,625	110,250	24	42.5
Stress Relieved	97,000	107,000	25	27.5
As Welded	105,125	113,000	24	46.5
Stress Relieved	93,000	101,000	22	28.0

Table 1 (Ref.1) Welding Electrode Properties

3.2 Plate

The qualification tests were made using plate from the Sheffield Div., Armco Steel Corp., Houston, Texas, manufactured and certified to meet the requirements of Specification MIL-S-`ᶜ 6F for HY100 steel. The chemical analysis is presented in table . The plate was austenitized at 1650°F, 120 minutes soak time, w·ter spray quenched, and tempered 120 minutes at 1170°F. The plate w 2 inches thick. Physical properties were as follows:

Heat Test	Y.S.(psi)	U.S.(psi)	% Elong. to 2"	% Red.Area	Charpy V-notch -120°F ft.lbs.
56433 2BT	107,400	120,700	21.0	65.2	
56433 2BB	106,500	119,700	21.0	71.2	84, 84, 86

Table 2 (Ref.2 and 3) Weld Qualification Plate Properties

Explosion bulge test specimens were submitted to the Material Laboratory, New York Naval Shipyard. (Ref.3)

3.3 Welder Qualification Results

Five welders were qualified per NAVSHIPS 250-637-3, J.L. Cross. Joe Mattern, Ike Gurka, Jones, J.D. Puddy.

Sample physical data follows (Ref.4).

Test	Stress Relief	Y.S.(psi)	U.S.(psi)	% Elong. in 2"	Charpy V-notch ft lbs
67SR-1	Yes	103,139	121,450	26.0	16.0, 24.5, 19.0(-120°F)
67SR-2	Yes	104,581	121,374	26.0	
43	No	105,000	120,577	32.0	24.0, 21.0, 24.0(-120°F)
1	Yes				69.5 (+72°F)
2	"				49.0 (0°F)
3	"				16.0 (-60°F)
4	"				24.5 (-60°F)
5	"				13.5 (-60°F)
6	"				19.0 (-60°F)
7	"				12.0 (-120°F)
8	"				7.0 (-120°F)
9	"				10.5 (-120°F)

All failures in parent metal
Stress relief at 1025 ±25°F for 3 1/2 hrs.

Table 3 (Ref.4) Weld Qualification Results

During fabrication, an additional sample weldment was made using the Sheffield plate discussed in paragraph 3.2 in order to furnish more data on the effect of stress relief on physical properties. The stress relief in this instance was 1025 ±25°F for 3 1/2 hours. Physical data from this weldment follow:

Specimen	Stress Relieved	Y.S.(psi)	U.S.(psi)	% Elong. in 2"	Charpy V-notch -120°F ft. lbs
1-17	No	101,496	117,877	20.0	
1-18,19,20	No				30.0, 38.0, 30.0
1-21	Yes	106,729	126,063	20.0	
1-22,23,24	Yes				17.5, 16.5 17.5

All failure in the parent metal

Table 4 (Ref.10) Weld Qualification Results Add'l.

A hardness survey of the above specimens 1-17 and 1-21 is included in Fig. 2 and 3. (Ref.11) It is noted that the hardness in the heat affected zone is less than that indicated in a weldment of Fig. 4 Ref. 25).

The weld procedure was prepared by the fabricator, Hahn & Clay, Houston, Texas, after consultation with General Mills, Inc., WHOI, and the Bureau of Ships, U.S. Navy.

Conclusions

Failure of the pressure hull can be judged to have occurred on the basis of two independent criteria. One, catastrophic collapse, and two, substantial local yielding which would make the hull unfit for further use.

Fracture toughness which affects both criteria of failure places Hull #3 the best and #1 the least superior of the 3 hulls. The static strength of the forgings and welds influences the yield mode of failure. All three hulls are equal in this respect. Ultimate collapse pressure is probably a function of basic shell strength and toughness. Hull #3 is slightly less strong in the basic shell than hulls #1 and 2 but Hull #3 is the toughest.

In summary, on the basis of mechanical properties, Hull #2 and #3 are considered superior to Hull #1.

Recommendations

1) Drop Weight Tear and Explosion Bulge Tests should be run using ALVIN hemisphere drops after stress relief at 1025° for 3 1/2 hours.

2) A program similar to that reported in Ref. 15 should be carried out to evaluate the expected performance of the ALVIN hull welds using welds made from ALVIN material with ALVIN welding rod.

3) Forging slab specimens presently at DTMB and WHOI should be stress relief heat treated and given Charpy V-notch and Drop Weight Tear test.

4) It is hoped that enough test information can be accumulated to establish the fracture analysis diagram (Ref.14) for the ALVIN hull materials.

Table 5

Chemical Analysis Data (Ref. 2, 6, 7, 8)

Manufacturer	Heat No	Use	C	Mn	P	S	Si	Ni	Cr	Mo	V	Cu	Ti
Sheffield-Armco	56433	Weld Qualification	.17	.32	.010	.017	.26	2.93	1.68	.47			
Lukens	B0091	Plate for Hemispheres	.18	.35	.008	.015	.30	3.29	1.60	.60	.004	.16	.014
Isaacson	2256	Forging Slabs	.19	.31	.012	.021	.27	3.27	1.59	.50	.024	.19	.006
Isaacson	2256	Forging Slabs Check Anal.	.18	.30	.010	.019	.28	3.30	1.62	.49	.02	.19	.005
Isaacson*	2256	Forging Slab 1 Check Anal.	.16	.30	.008	.017	.27	3.15	1.75	.50	.00	.15	.00
Isaacson*	2256	Forging Slab 2 Check Anal.	.18	.29	.016	.022	.26	3.16	1.76	.50	.00	.16	.00
" *	"	Forging Slab 3 Check Anal.	.18	.27	.009	.021	.27	3.13	1.74	.50	.00	.16	.00
" *	"	Forging Slab 4 Check Anal.	.18	.30	.013	.023	.25	3.13	1.75	.50	.00	.15	.00
" *	"	Forging Slab 5 Check Anal.	.18	.27	.012	.018	.27	3.13	1.77	.51	.00	.16	.00
Lukens*	B0091	Spun Hemisphere 2B1	.22	?	.007	.017	.33	3.29	1.57	.68	.00	.15	.00
" *	"	Spun Hem. 2B2	.19	.33	.007	.017	.33	3.21	1.57	.63	.00	.15	.00
" *	"	" " 3B1	.20	.35	.008	.017	.34	3.26	1.57	.68	.00	.14	.00
" *	"	" " 3B2	.20	.35	.011	.016	.36	3.27	1.58	.68	.00	.14	.00
" *	"	" " 4B1	.20	.35	.009	.015	.34	3.27	1.58	.69	.00	.14	.00
" *	"	" " 4B2	.19	.35	.006	.015	.31	3.17	1.57	.68	.00	.15	.00
McKay	QC1350	1/8" W.R.	.06	1.70	.012	.017	.36	1.75	.01	.37	.01		
McKay E11018 Electrode	QC13274	3/16"W.R.	.045	1.46	.012	.020	.28	1.55	.01	.37	.01		
McKay E11018 Electrode	QC12462	5/32"W.R.	.050	1.56	.012	.019	.29	1.65	.01	.40	.01		
HY100 per MILS-	16216F	(SHIPS)	Max. .20	.10 – .40	Max. .025	Max. .025	.15 – .35	2.25 – 3.50	1.00 – 1.80	.20 – .60	Max. .03	Max. .25	Max. .02
E11018 Electrode per MIL-E-22200/1B			Max. .10	1.30 – 1.80	Max. .030	Max. .030	Max. .60	1.25 – 2.50	Max. .40	.30 – .55	Max. .05		

Table 6a Mechanical Properties of Hull No. 1

HEMISPHERE 381 (SOUTH POLE, WINDOWS) HEMISPHERE 481 (NORTH POLE, HATCH)		TENSION UNLESS C		S-S CURVE	% ELONG.	% R.A.	FRACTURE	TEST NO	V-NOTCH CHARPY °F (10 mm. x 10 mm.)			
PIECE	TEST NO.	0.2 % OFFSET Y.S. (PSI)	U.S. (PSI)						-120	-60	+30	+80
HEMISPHERE 381 LUKENS EDGE STOCK	LUKENS TRANS. 900H	110,500	130,800	YES	24	64.1						
"	LUKENS LONG. 901H	114,500	132,700	YES	23	61.4			35 40 40			
HEMISPHERE 481 LUKENS EDGE STOCK	LUKENS TRANS. 902H	108,400	127,200	YES	22	58.1						
"	LUKENS LONG. 903H	107,600	126,500	YES	22	60.2			46 42 40			
FRONT WINDOW DROP HEM. 381 - NOT STRESS RELIEVED	SOU'WSTRN 1-9N	112,178	129,864	NO	21	65.9		1-10 1-11N 1-12	38 29.5 29.5			
"	1-13 E	111,978	130,347	NO	20	55.7		1-14 1-15E 1-16	30 24 25			
FRONT WINDOW DROP HEM. 381, STRESS RELIEVED WITH NO. 2 HULL	1-1 N	113,283	131,328	YES	19	52.9		1-2 1-3 N 1-4	9.0 10.0 4.5			
"								1-2A 1-3A N 1-4A	9.0 7.5		33	
"	1-5E	112,782	130,827	YES	21	62.2		1-6 1-7 E 1-8	12 12			
"								1-6A 1-7A E 1-8A	— 7.0		40.0	
HATCH DROP H. + C. DWG. SK-1572A, HEM. 481 NOT STRESS RELIEVED	1-25 E	111,223	129,467	YES	22	65.8		1-26 1-27 E 1-28	32		80 75	
"	1-29 N	111,278	128,574	YES	22	63.9		1-30 1-31 N 1-32	20.5		70 74	
HEM. 481, HATCH DROP NOT STRESS RELIEVED DTMB	DTMB CIRCUM. E 33-1	COMP. 117,574	—	YES								
"	DTMB MERID. N 34-1	COMP. 119,131	—	YES								

Table 6b Mechanical Properties of Hull No. 1

HEMISPHERE 3B1 (SOUTH POLE, WINDOWS) HEMISPHERE 4B1 (NORTH POLE, HATCH)		TENSION UNLESS C		S-S CURVE	% ELONG.	% R. A.	FRACTURE	TEST NO.	V-NOTCH CHARPY °F (10 mm. x 10 mm.)			
PIECE	TEST NO.	0.2 % OFFSET Y. S. (PSI)	U. S. (PSI)						-120	-60	+30	+80
WINDOW INSERT FORGINGS	ISAACSON L 2084-2A	105,000	119,500	NO	21	67	$\frac{1}{2}$ C.	TOP	35 36 30			
SLAB 2	T 2084-2A	107,500	120,000	NO	20	61.8	F.C.					
	L 2084-2B	113,500	125,000	NO	18.5	55.7	$\frac{1}{2}$ C.	BOTTOM	30 32 39			
	T 2084-2B	111,000	125,500	NO	18.5	54.9	F.C.					
HATCH INSERT FORGING	2084-1AL	114,000	125,500	NO	19	56	$\frac{1}{2}$ C.	TOP	45 30 36			
SLAB 1	2084-1AT	113,500	125,500	NO	20	60.3	$\frac{1}{2}$ C.					
	2084-1BL	115,000	126,500	NO	21	68.6	STAR	BOTTOM	41 39 38			
	2084-1BT	114,500	124,750	NO	19.5	57.8	$\frac{1}{2}$ C.					
HATCH PLUG FORGING	2084-3AL	111,500	124,500	NO	18.5	55.5	$\frac{1}{2}$ C.	TOP	44 41 50			
SLAB 3	2084-3AT	112,000	124,500	NO	21	69.3	F.C.					
	2084-3BL	110,000	121,500	NO	20	65.2	F.C.	BOTTOM	40 40 44			
	2084-3BT	113,000	123,000	NO	18	57.5	$\frac{2}{3}$ C.					

Table 6c Mechanical Properties of Hull No. 2

HEMISPHERE 2B2 (SOUTH POLE, WINDOWS) HEMISPHERE 2B1 (NORTH POLE, HATCH)		TENSION UNLESS C		S-S CURVE	% ELONG.	% R.A	FRACTURE	TEST NO.	V-NOTCH CHARPY °F (10 mm. x 10 mm.)			
PIECE	TEST NO.	0.2 % OFFSET Y.S. (PSI)	U.S. (PSI)						-120	-60	+30	+80
HEMISPHERE 2B2 LUKENS EDGE STOCK	LUKENS T	114,500	130,000	YES	21	67.3						
"	L	113,100	132,800	YES	21	64.7			53 54 40			
HEMISPHERE 2B1 LUKENS EDGE STOCK	T	109,300	131,800	YES	21	56.2						
"	L	112,800	132,500	NO	21	57			53 41 46			
FRONT WINDOW DROP HEM. 2B2, NOT STRESS RELIEVED	SOU'WSTRN 2-9 N	108,203	123,050	NO	23	72.5		2-10 2-11 N 2-12	53 45.5 37.5			
"	2-13 E	105,184	121,288	YES	22	69.5		2-14 2-15 E 2-16	33.5 21.5 34.5			
FRONT WINDOW DROP HEM. 2B2, STRESS RELIEVED WITH NO. 2 HULL	2-1 N	110,025	124,687	YES	22	69.6		2-2 2-3 N 2-4	12.5 15.5 17.0			
"	2-5 E	110,025	125,313	YES	21	65.5		2-5 2-6 E 2-7	17.5 15.0 13.0			
HATCH DROP H.+C. DWG. SK-1972A, HEM. 2B1 NOT STRESS RELIEVED	2-25 E	112,984	129,718	YES	19	58.3		2-26 2-27 E 2-28	27.0		57.0 57.5	
"	2-29 N	112,281	130,075	YES	22	62.7		2-30 2-31 N 2-32	43		69.0 67.5	
HEM. 2B1, HATCH DROP NOT STRESS RELIEVED DTMB	DTMB CIRCUM. E. 33-2	COMP. 117,927	–	YES	–	–						
"	DTMB MERID. N. 34-2	COMP. 119,820	–	YES	–	–						

Table 6d Mechanical Properties of Hull No. 2

HEMISPHERE 2B2 (SOUTH POLE, WINDOWS) HEMISPHERE 2B1 (NORTH POLE, HATCH)		TENSION UNLESS C		S-S CURVE	% ELONG.	% R.A.	FRACTURE	TEST NO.	V-NOTCH CHARPY °F (10 mm. x 10 mm.)			
PIECE	TEST NO.	0.2 % OFFSET Y.S. (PSI)	U.S. (PSI)						-120	-60	+30	+80
WINDOW INSERT FORGINGS	ISAACSON 2084-5AL	104,000	118,250	YES	23.0	69.0	F.C.	TOP	66 60 68			
FRONT, STBD., BOTTOM WINDOWS, SLAB 5	2084-5AT	104,000	117,750	YES	21.0	61.8	½ C.					
	2084-5BL	105,000	118,000	YES	24.0	71.4	F.C.	BOTTOM	54 58 58			
	2084-5BT	105,000	118,000	YES	21.0	58.3	½ C.					
PORT WINDOW, SLAB 4	2084-4AL	105,500	118,500	YES	24.0	71.0	STAR	TOP	58 54 58			
	2084-4AT	106,500	120,000	YES	21.0	60.8	½ C.					
	2084-4BL	100,866	114,111	YES	23.0	68.4	STAR	BOTTOM	56 52 52			
	2084-4BT	104,000	117,000	YES	20.0	57.8	½ C.					
HATCH INSERT FORGING SLAB 1	SEE	HULL 1										
HATCH PLUG FORGING SLAB 3	SEE	HULL 1										

Table 6e Mechanical Properties of Hull No. 3

HEMISPHERE 4B2 (SOUTH POLE, WINDOWS) HEMISPHERE 3B2 (NORTH POLE, HATCH)		TENSION UNLESS C		S-S CURVE	% ELONG.	% R. A	FRACTURE	TEST NO.	V-NOTCH CHARPY °F (10 mm. x 10 mm.)			
PIECE	TEST NO.	0.2 % OFFSET Y. S. (PSI)	U. S. (PSI)						-120	-60	+30	+80
HEMISPHERE 4B2 LUKENS EDGE STOCK	LUKENS T	113,000	133,700	NO	22	66.3						
"	L	109,600	129,900	NO	24	64.0			54 51 48			
HEMISPHERE 3B2 LUKENS EDGE STOCK	T	102,200	119,000	YES	22	66.0						
"	L	105,600	123,000	YES	22	64.5			60 58 69			
FRONT WINDOW DROP HEM. 4B2, NOT STRESS RELIEVED	SOU'WSTRN 3-9 N	107,700	124,434	NO	22			3-10 3-11 N 3-12	34.5 29.0 32.0			
"	3-13 E	107,052	124,556	NO	22			3-14 3-15 E 3-16	41.5 29.5 38.5			
FRONT WINDOW DROP HEM. 4B2, STRESS RELIEVED WITH HULL NO. 2	3-1 N	106,516	125,063	YES	23	64.6		3-2 3-3 N 3-4	17.5	22		72
"	3-5 E	106,694	125,063	YES	21	60.3		3-6 3-7 E 3-8	18.5	22		53.5
HATCH DROP H.+C. DWG. SK-1972A, HEM. 3B2 NOT STRESS RELIEVED	3-25 E	106,620	124,053	NO	22			3-26 3-27 E 3-28	34.5		67.5 67.5	
"	3-29 N	107,489	124,300	NO	22			3-30 3-31 N 3-32	46		81.5 76.5	
HEM. 3B2, HATCH DROP NOT STRESS RELIEVED DTMB	DTMB CIRCUM. E. 33-3	COMP. 113,455	—	YES	—	—						
"	DTMB MERID. N 34-3	COMP. 112,082	—	YES	—	—						

Table 6f Mechanical Properties of Hull No. 3

HEMISPHERE 4B2 (SOUTH POLE, WINDOWS) HEMISPHERE 3B2 (NORTH POLE, HATCH)		TENSION UNLESS C		S-S CURVE	% ELONG.	% R.A.	FRACTURE	TEST NO.	V-NOTCH CHARPY °F (10 mm. x 10 mm.)			
PIECE	TEST NO.	0.2 % OFFSET Y.S. (PSI)	U.S. (PSI)						-120	-60	+30	+80
WINDOW INSERT FOR INGS												
FRONT, STBD., BOTTOM WINDOWS; SLAB 4		SEE	HULL 2									
PORT WINDOW SLAB 5		SEE	HULL 2									
HATCH INSERT FORGING SLAB 1		SEE	HULL 1									
HATCH PLUG FORGING SLAB 3		SEE	HULL 1									

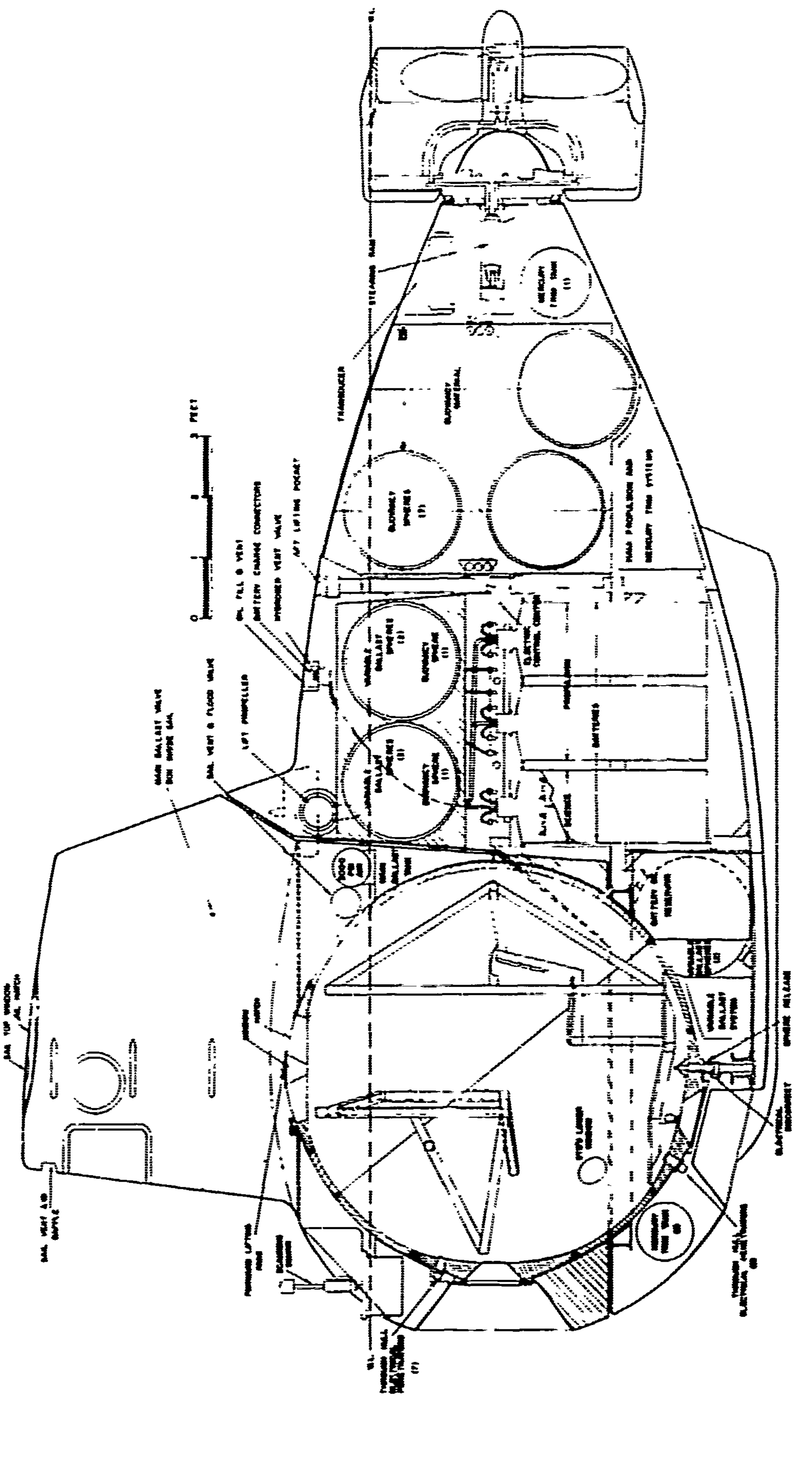
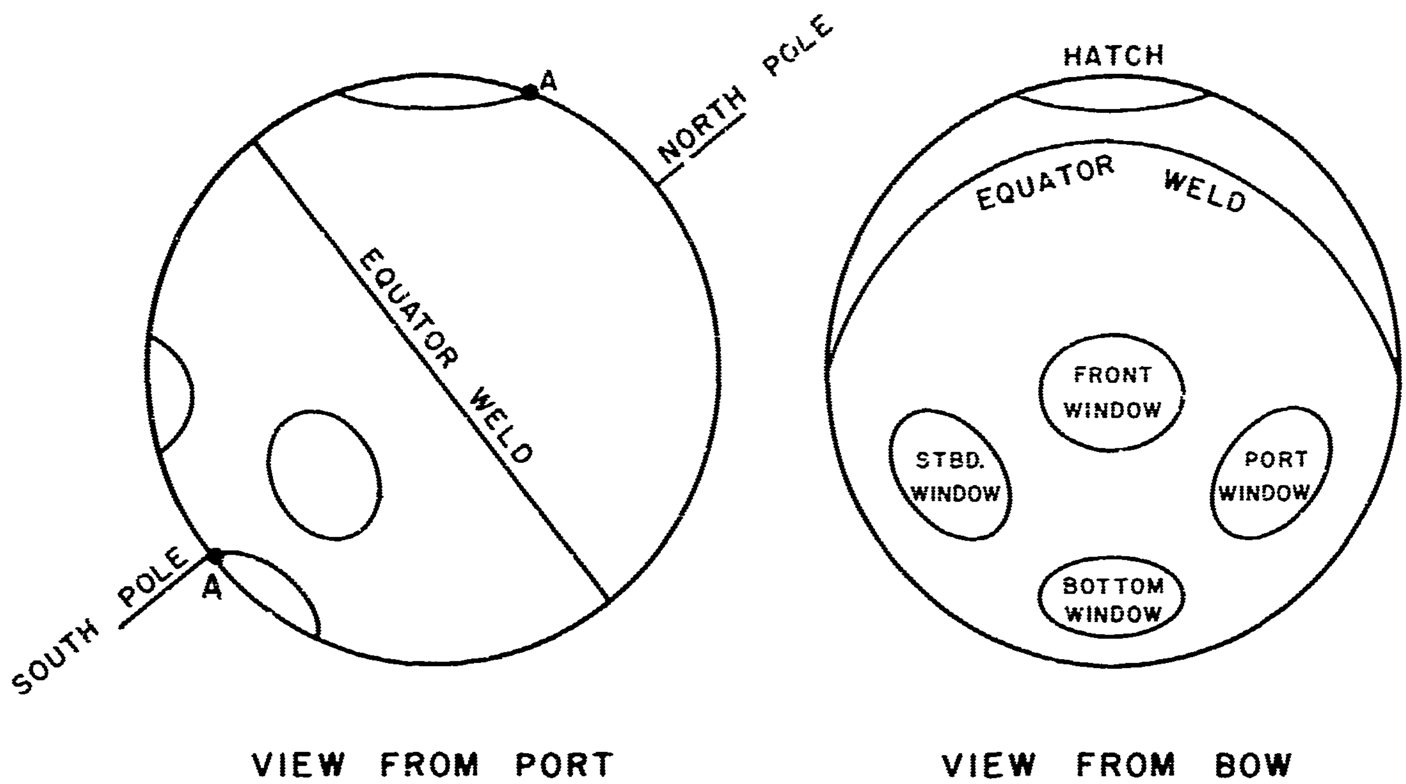


Fig. 1 ALVIN Inboard Profile



	WINDOW HEMISPHERE	HATCH HEMISPHERE
HULL NO. 1	3B1	4B1
HULL NO. 2	2B2	2B1
HULL NO. 3	4B2	3B2

EQUATOR WELD IS WELD NO. 1

FORGINGS	WELD NO.	HULL NO. 1		HULL NO. 2		HULL NO. 3	
		PIECE	SLAB	PIECE	SLAB	PIECE	SLAB
FRONT WINDOW INSERT	3	1	2	10	5	7	4
PORT " "	4	3	2	6	4	9	5
BOTTOM " "	5	2	2	12	5	5	4
STBD. " "	6	4	2	11	5	8	4
HATCH INSERT	2	1	1	2	1	3	1
" PLUG	–	1	3	2	3	3	3

Fig. 2 Sphere Nomenclature

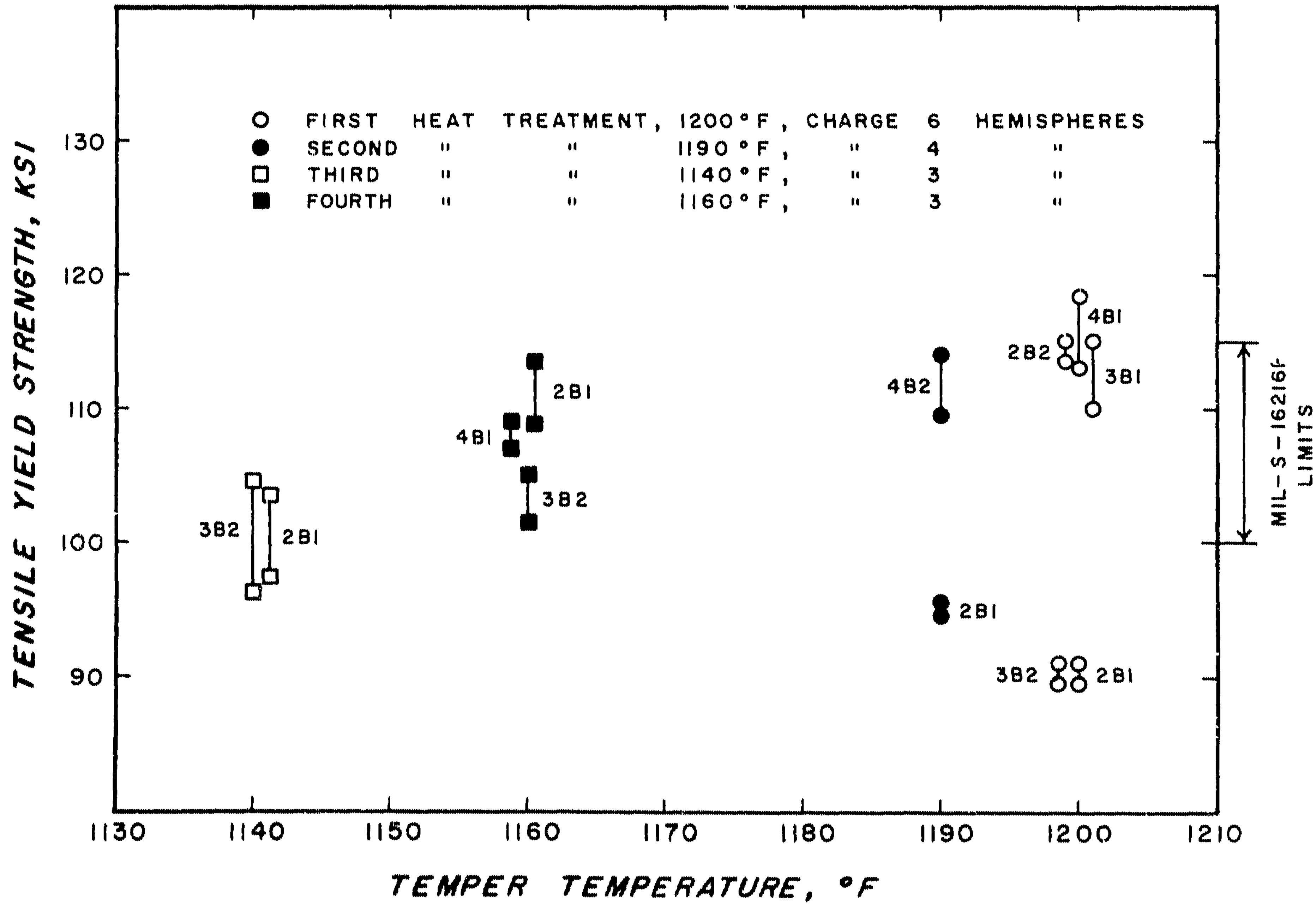


Fig. 3 Tempering Heat Treat History

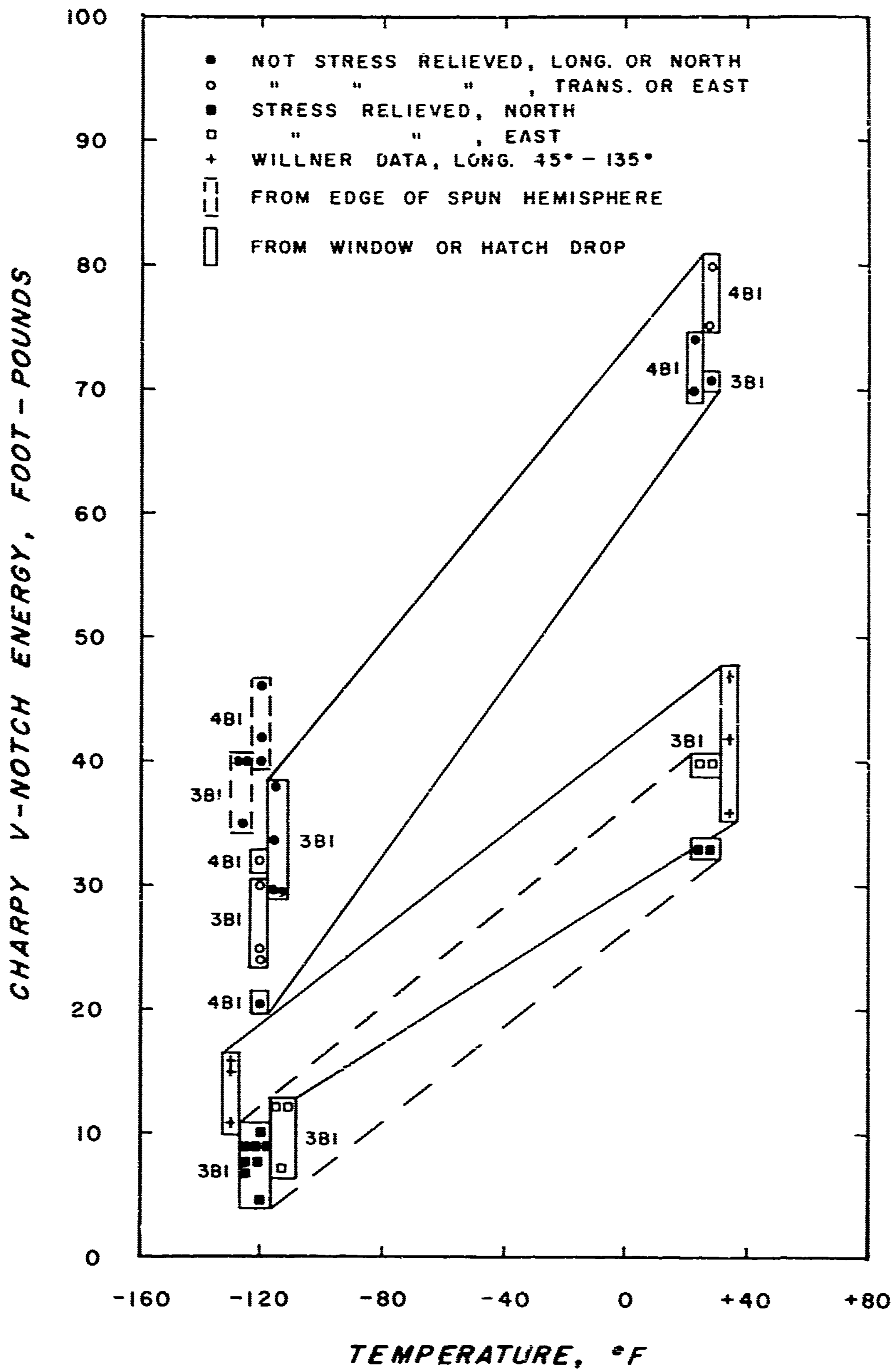


Fig. 4 V-Notch Charpy Data Hull No. 1

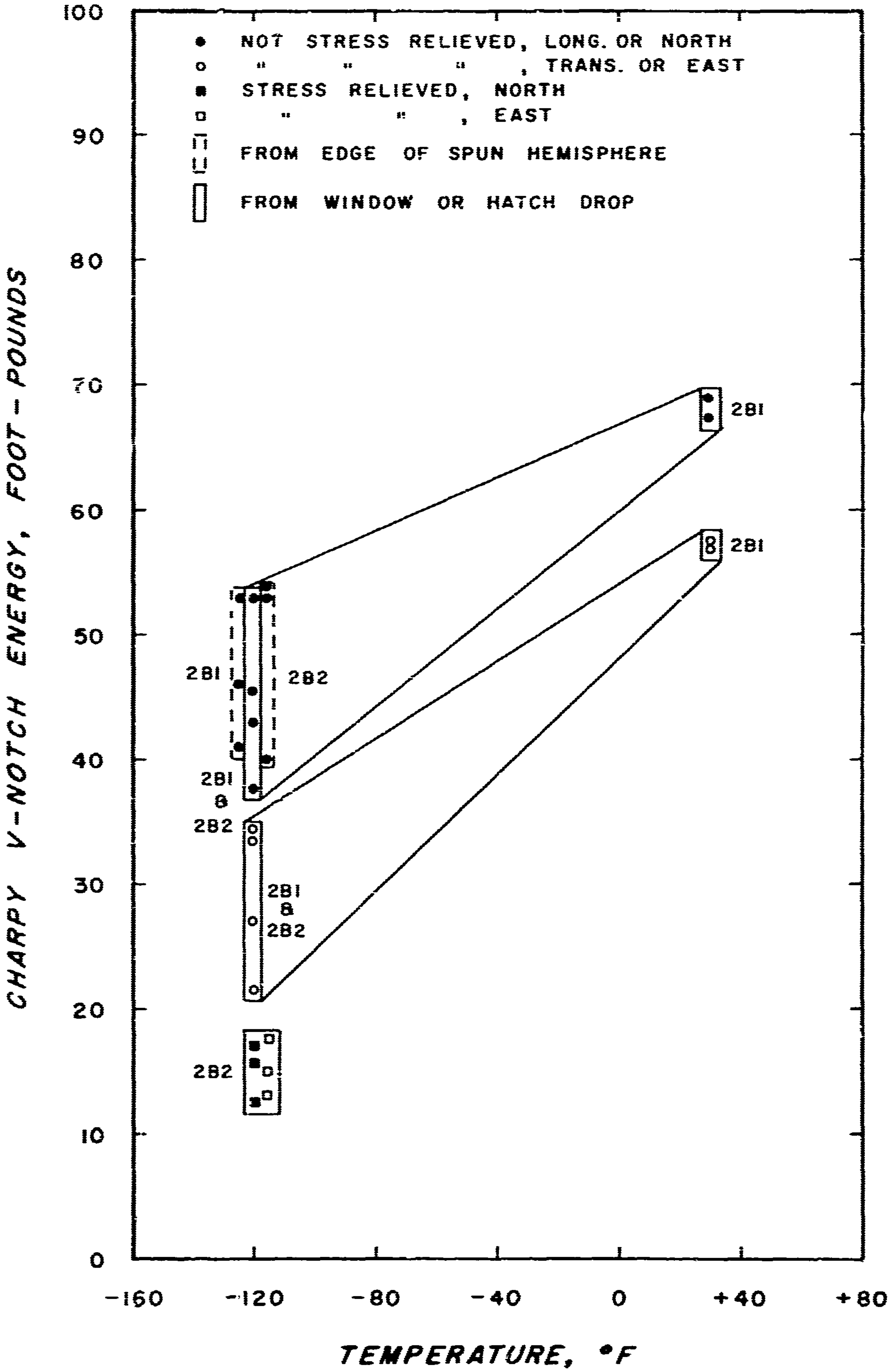


Fig. 5 V-Notch Charpy Data Hull No. 2

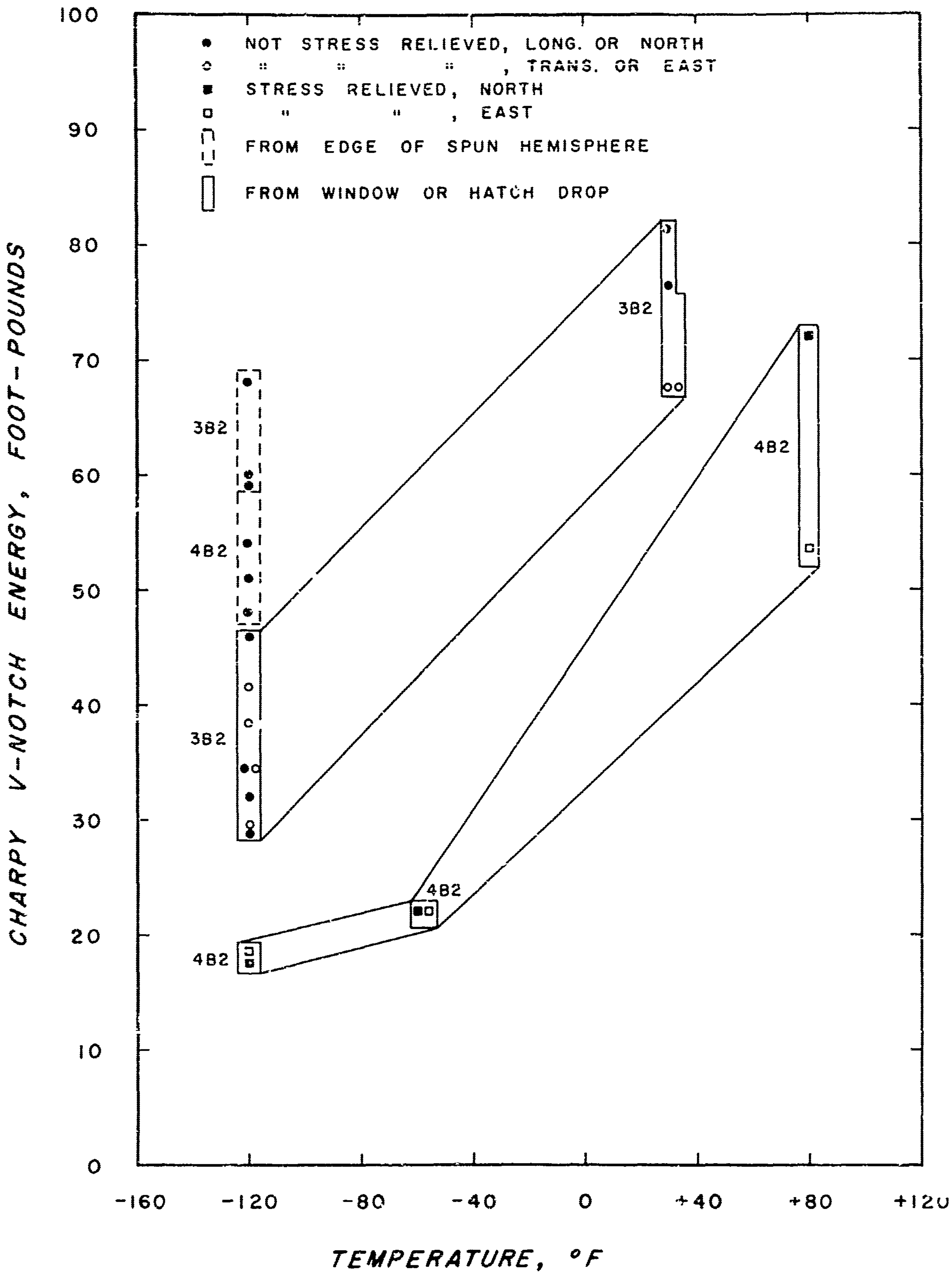


Fig. 6 V-Notch Charpy Data Hull No. 3

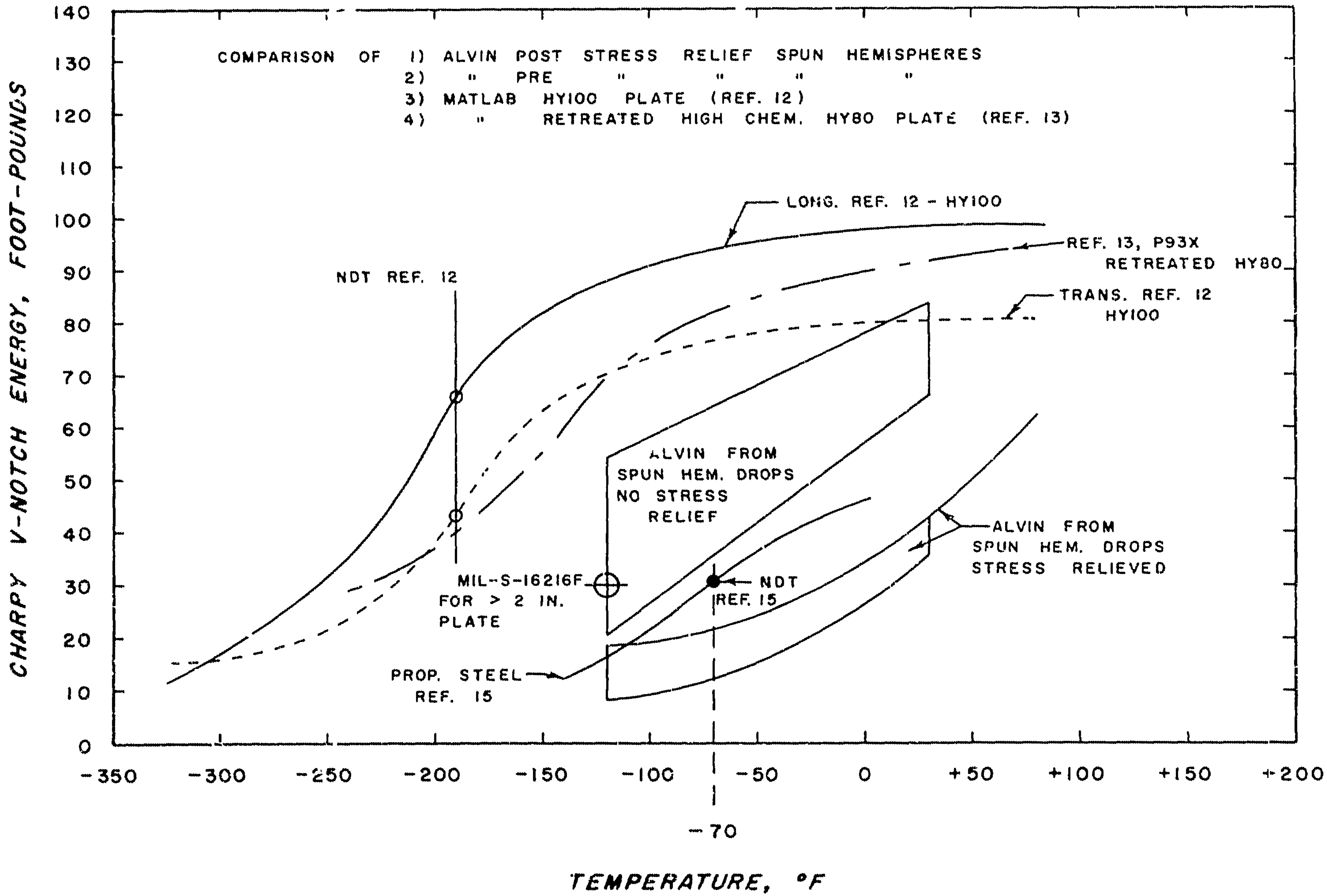
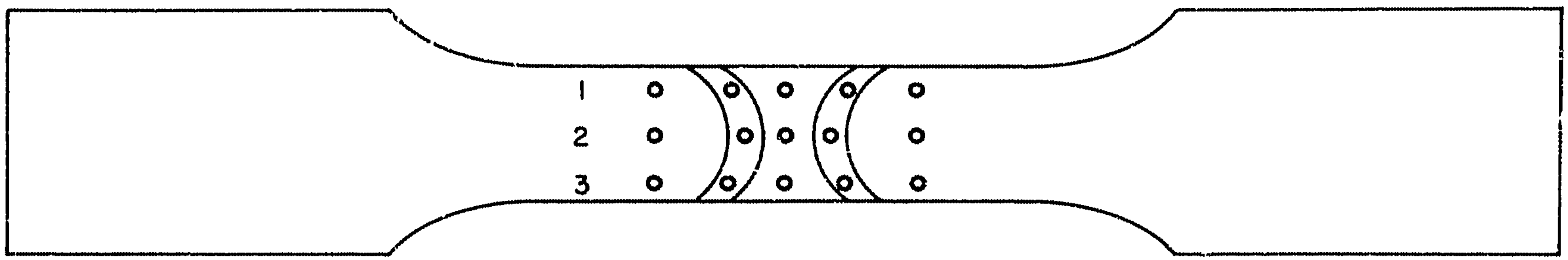


Fig. 7 Comparison of V-Notch Charpy Data

MATERIAL : 1.33 IN. THICK HY100 STEEL PLATE

NOT STRESS RELIEVED



SPECIMEN NO. 1-17

ROCKWELL 'C' HARDNESS SURVEY

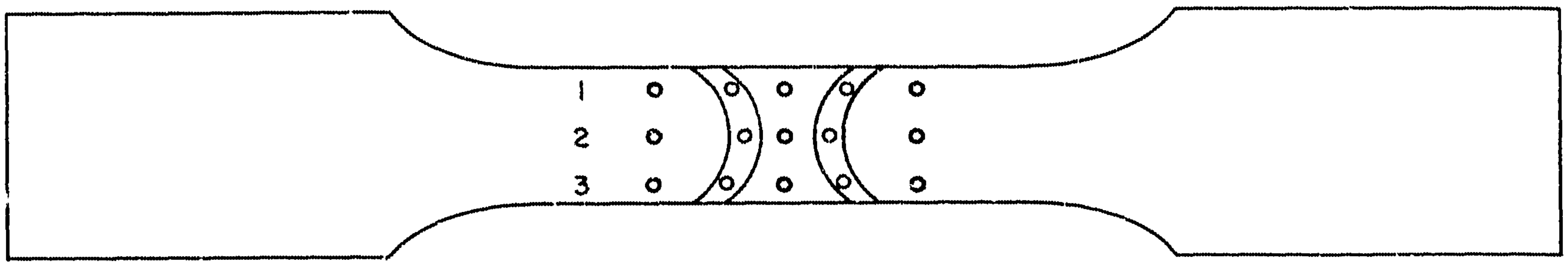
LINE NO.	PARENT METAL	HEAT EFF. ZONE	WELD METAL	HEAT EFF. ZONE	PARENT METAL
1	25.0	40.5	28.5	36.5	24.0
2	24.0	39.5	26.5	34.5	24.0
3	22.0	38.0	23.5	38.5	23.5

SOUTHWESTERN LABORATORIES
HOUSTON, TEXAS
AUGUST, 1963

Fig. 8 Hardness Survey Spec. 1-17

MATERIAL : 1.33 IN. THICK HY100 STEEL PLATE

STRESS RELIEVED AT 1025 °F



SPECIMEN NO. 1-21

ROCKWELL 'C' HARDNESS SURVEY

LINE NO.	PARENT METAL	HEAT EFF. ZONE	WELD METAL	HEAT EFF. ZONE	PARENT METAL
1	24.5	38.0	26.5	38.0	23.0
2	25.0	39.0	26.0	36.5	24.0
3	25.5	35.5	24.5	39.5	23.0

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HOUSTON, TEXAS
AUGUST, 1963

Fig. 9 Hardness Survey Spec. 1-21

Fig. 10 Load Deflection Curves

10-1	Hem.	3B1	Long.	Hull 1	Lukens Hem Edge Data
10-2	"	3B1	Trans.		
10-3	"	4B1	Long.		
10-4	"	4B1	Trans.		
10-5	"	2B2	Long.	Hull 2	
10-6	"	2B2	Trans.		
10-7	"	2B1	Trans		
10-8	"	3B2	Long.	Hull 3	
10-9	"	3B2	Trans.		
10-10	"	4B1	North	Hull 1	DTMB Compressive Data Hatch Drops
10-11	"	4B1	East		
10-12	"	2B1	North	Hull 2	
10-13	"	2B1	East		
10-14	"	3B2	North	Hull 3	
10-15	"	3B2	East		
10-16	"	4B1	East	Hull 1	Not Stress Relieved Southwestern Drops
10-17	"	4B1	North		
10-18	"	2B1	East	Hull 2	
10-19	"	2B1	North		
10-20	"	2B2	East		
10-21	"	3B1	North	Hull 1	Stress Relieved Southwestern Drops
10-22	"	3B1	East		
10-23	"	2B2	North	Hull 2	
10-24	"	2B2	East		
10-25	"	4B2	North	Hull 3	
10-26	"	4B2	East		

10-27	Forgings	Slab 4
10-28	Forgings	Slab 5

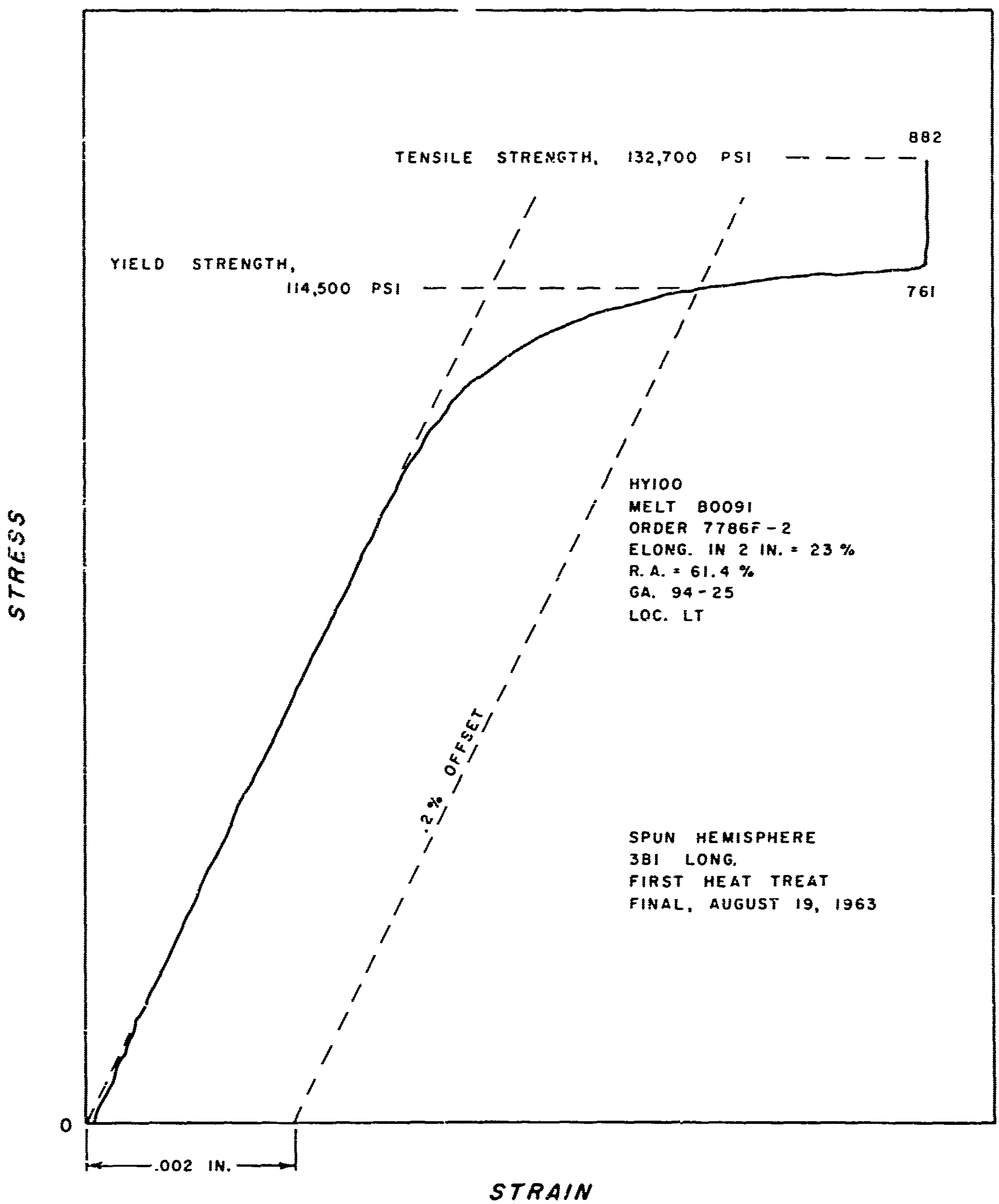


Fig. 10-1 Load Deflection Curve

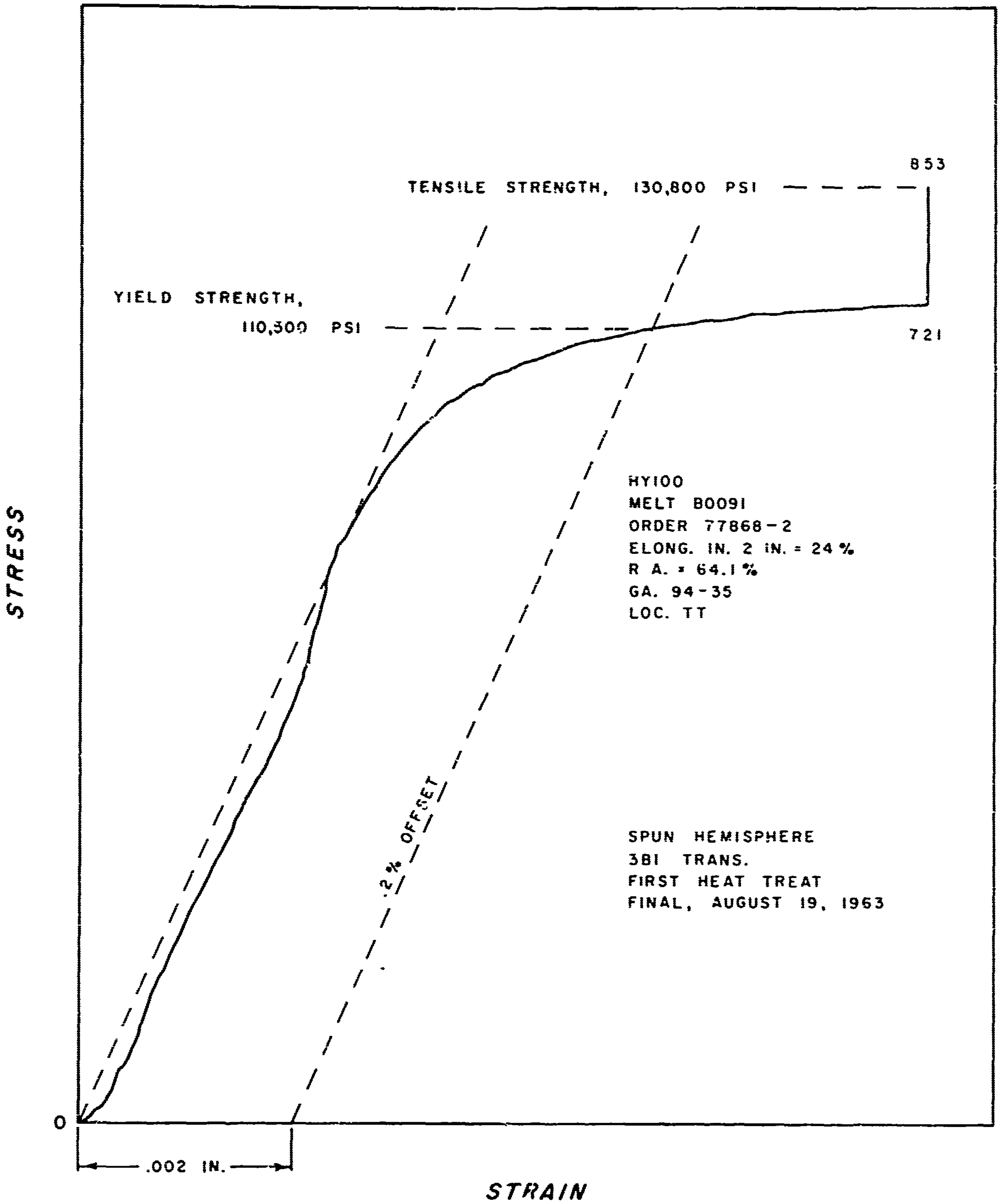


Fig. 10-2 Load Deflection Curve

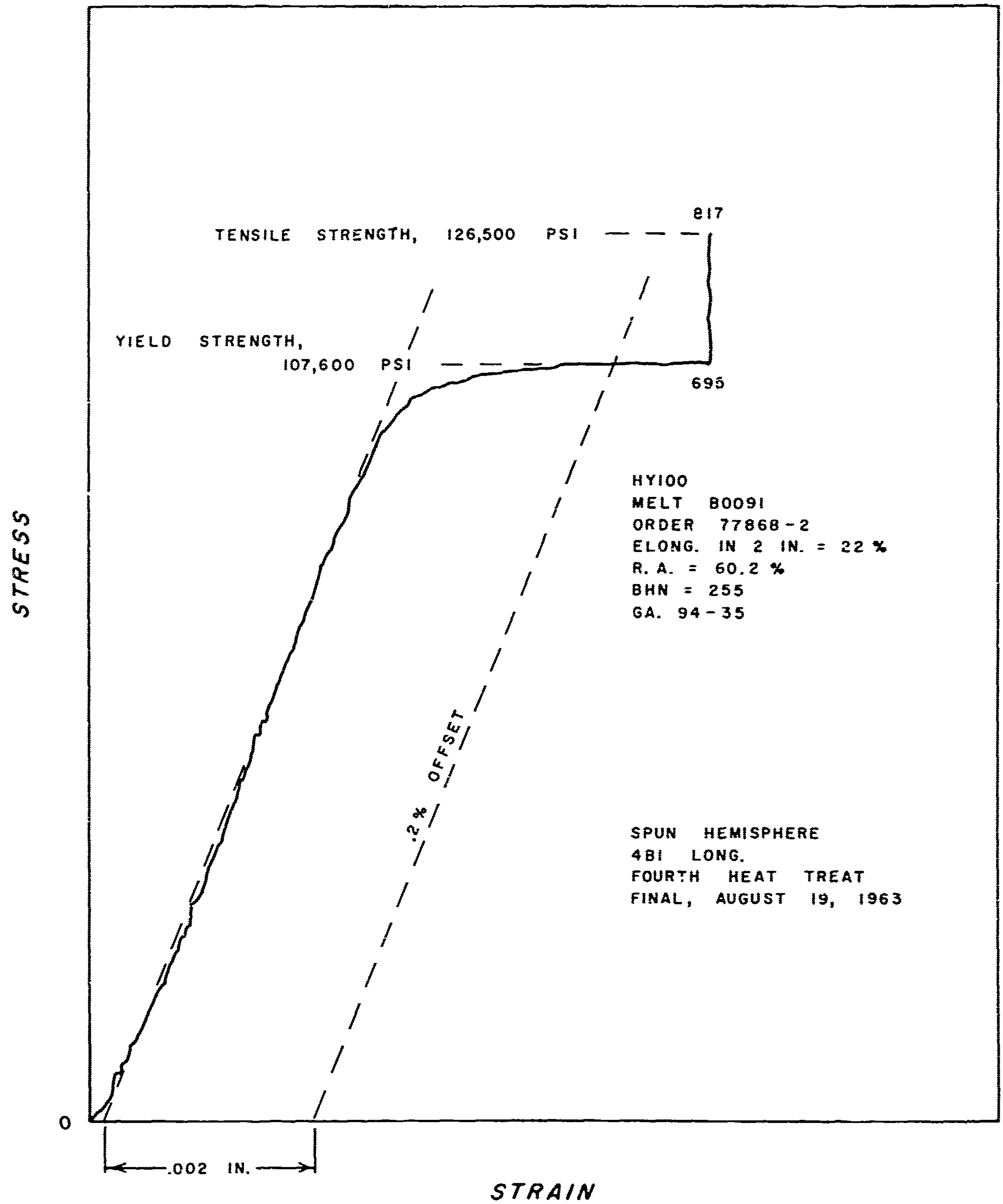


Fig. 10-3 Load Deflection Curve

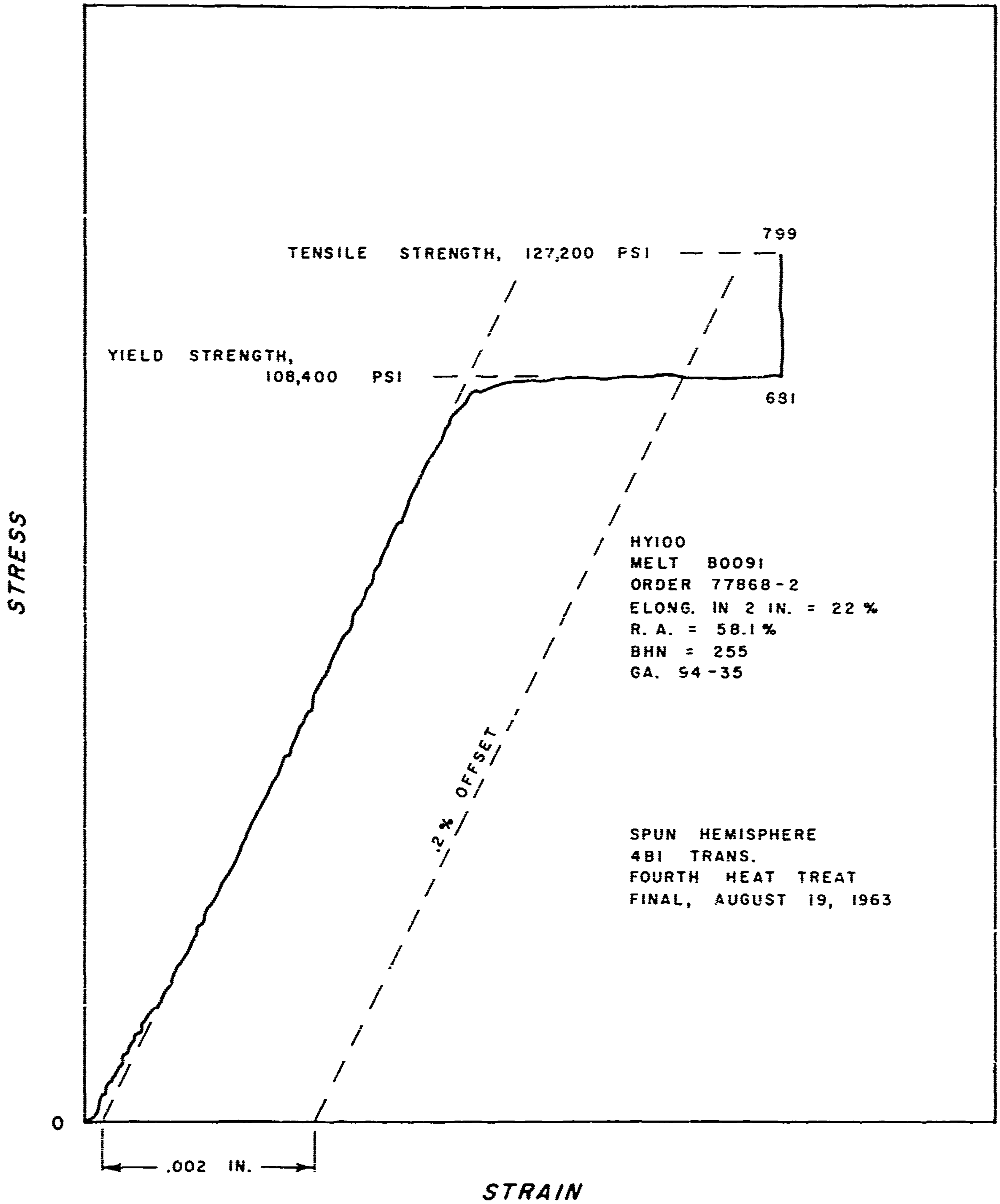


Fig. 10-4 Load Deflection Curve

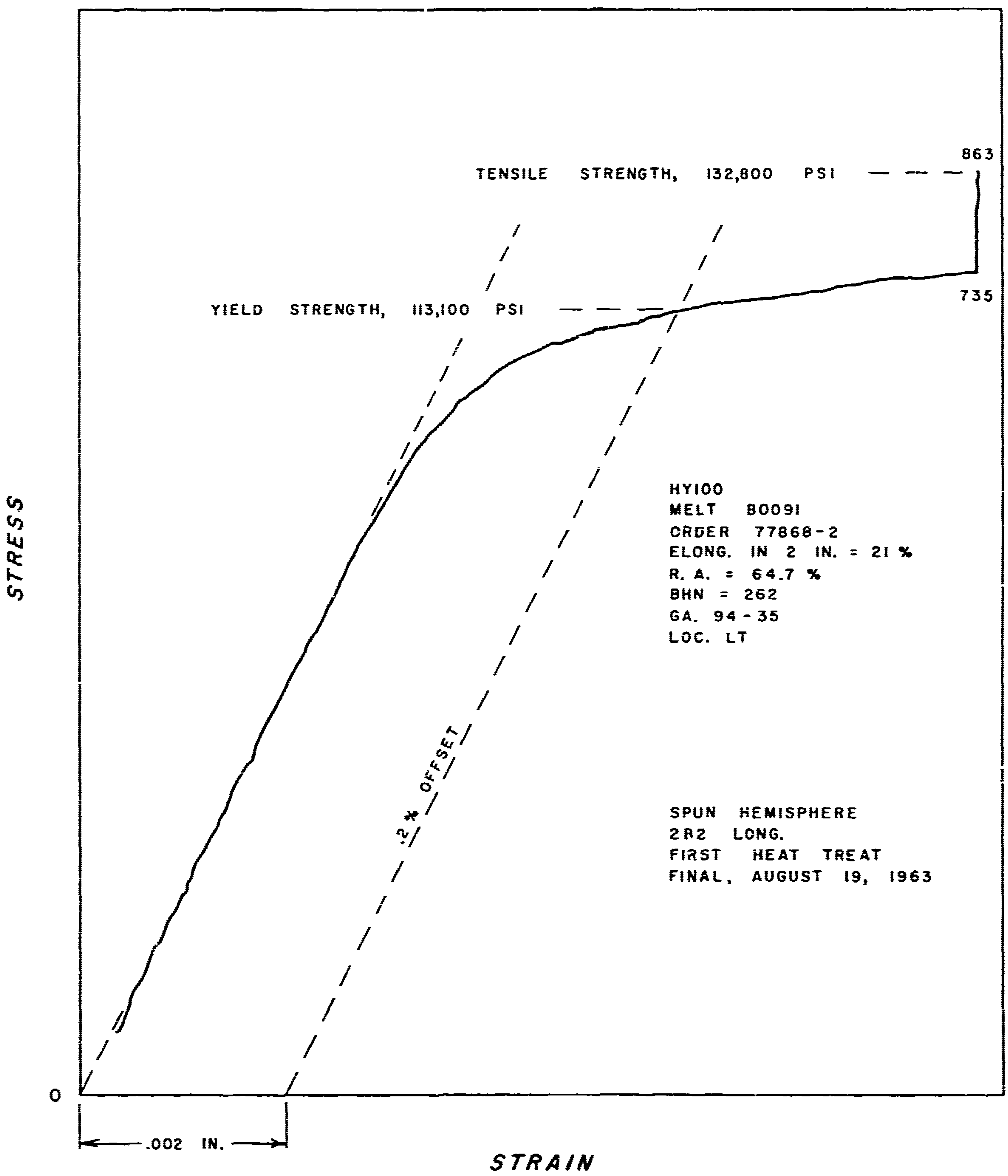


Fig. 10-5 Load Deflection Curve

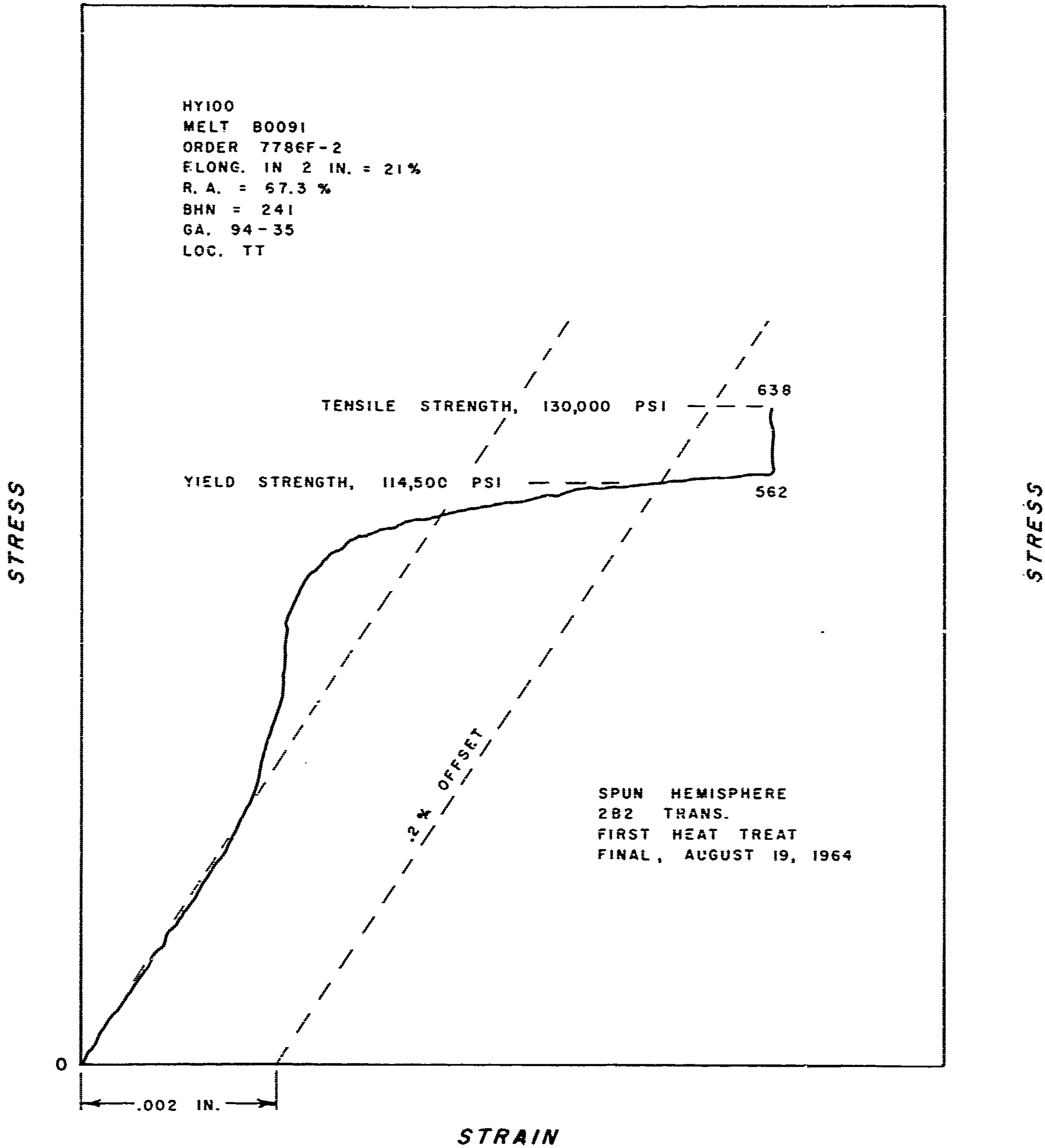


Fig. 10-6 Load Deflection Curve

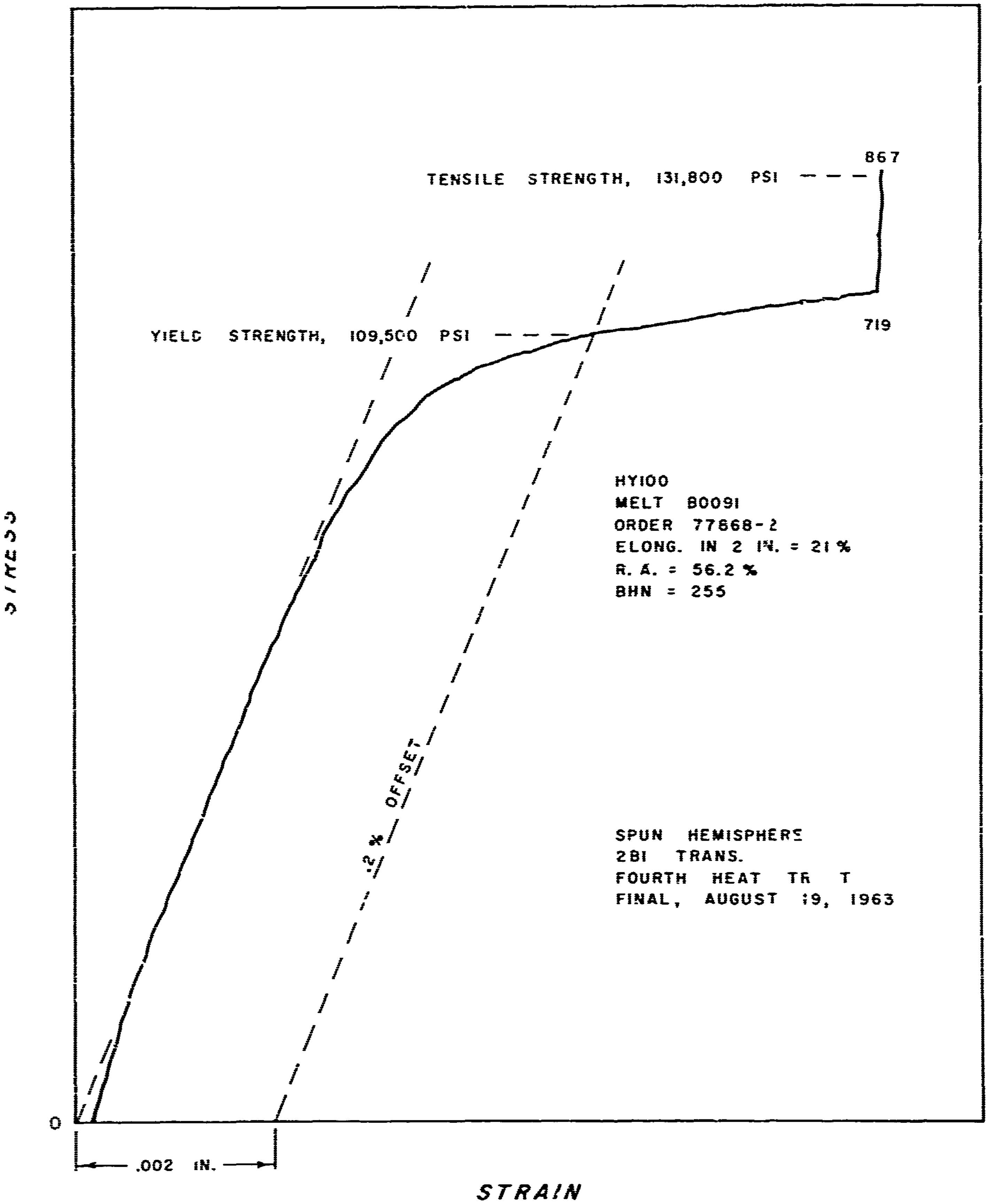


Fig. 10-7 Load Deflection Curve

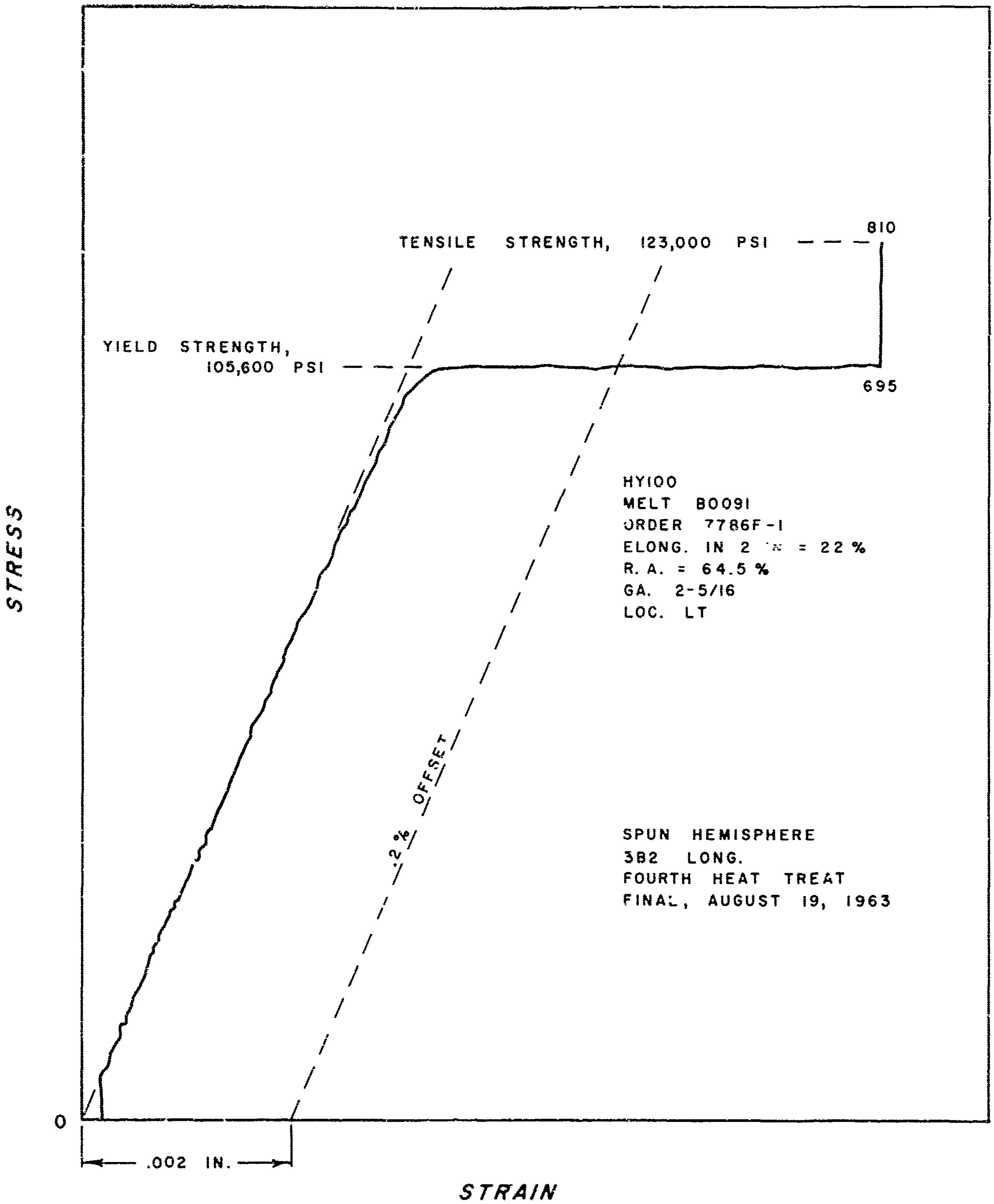


Fig. 10-8 Load Deflection Curve

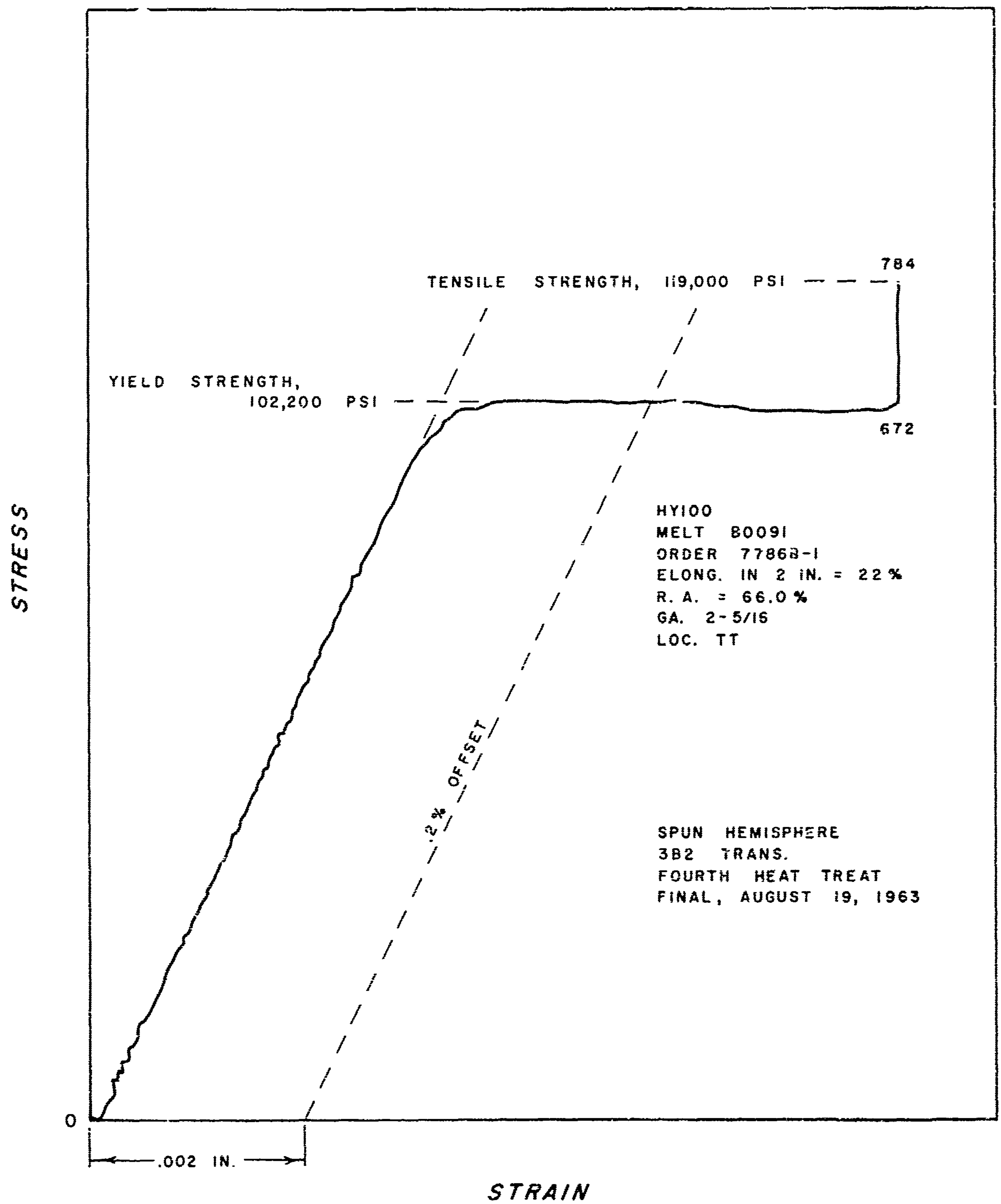


Fig. 10-9 Load Deflection Curve

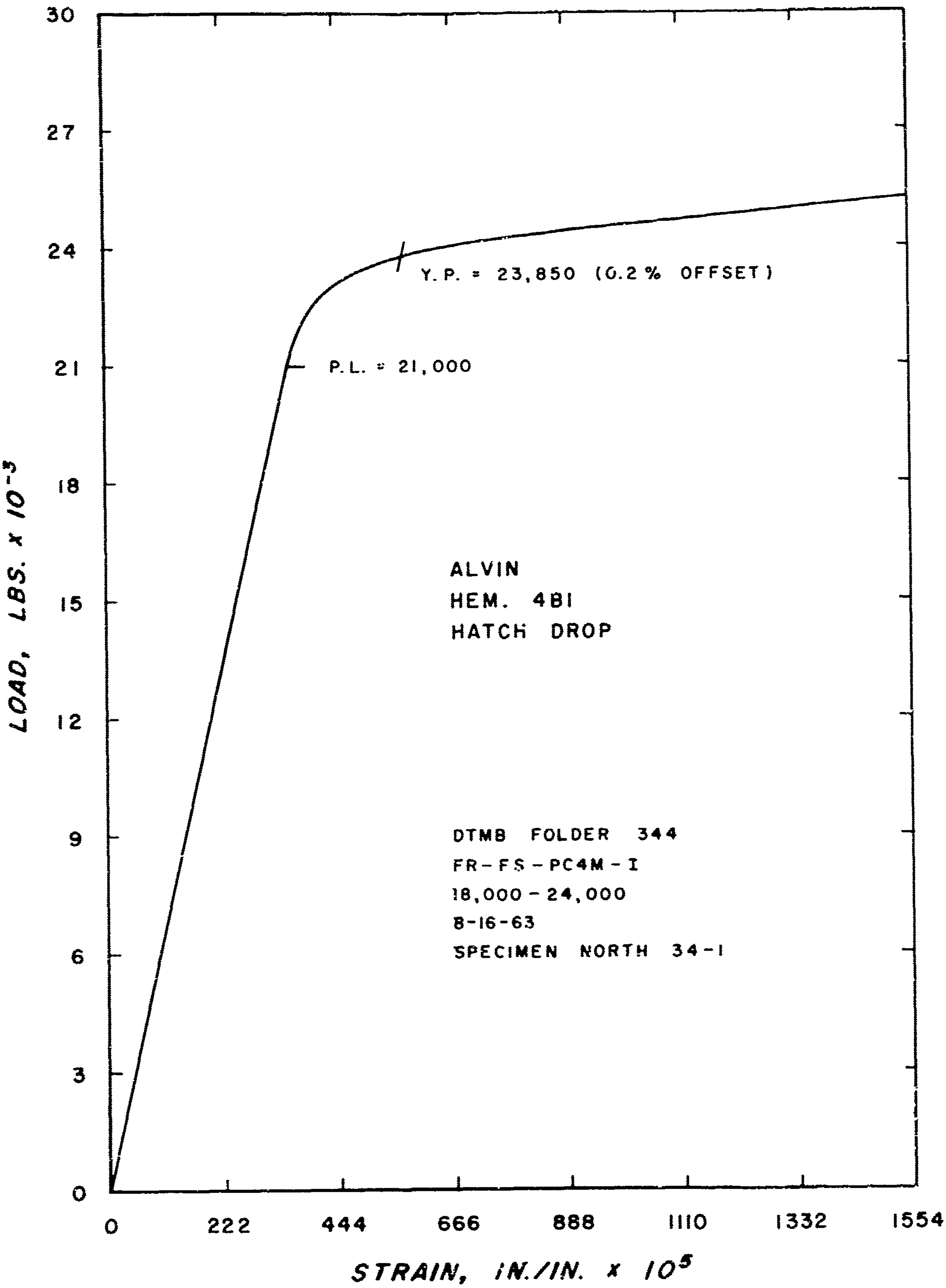


Fig. 10-10 Load Deflection Curve

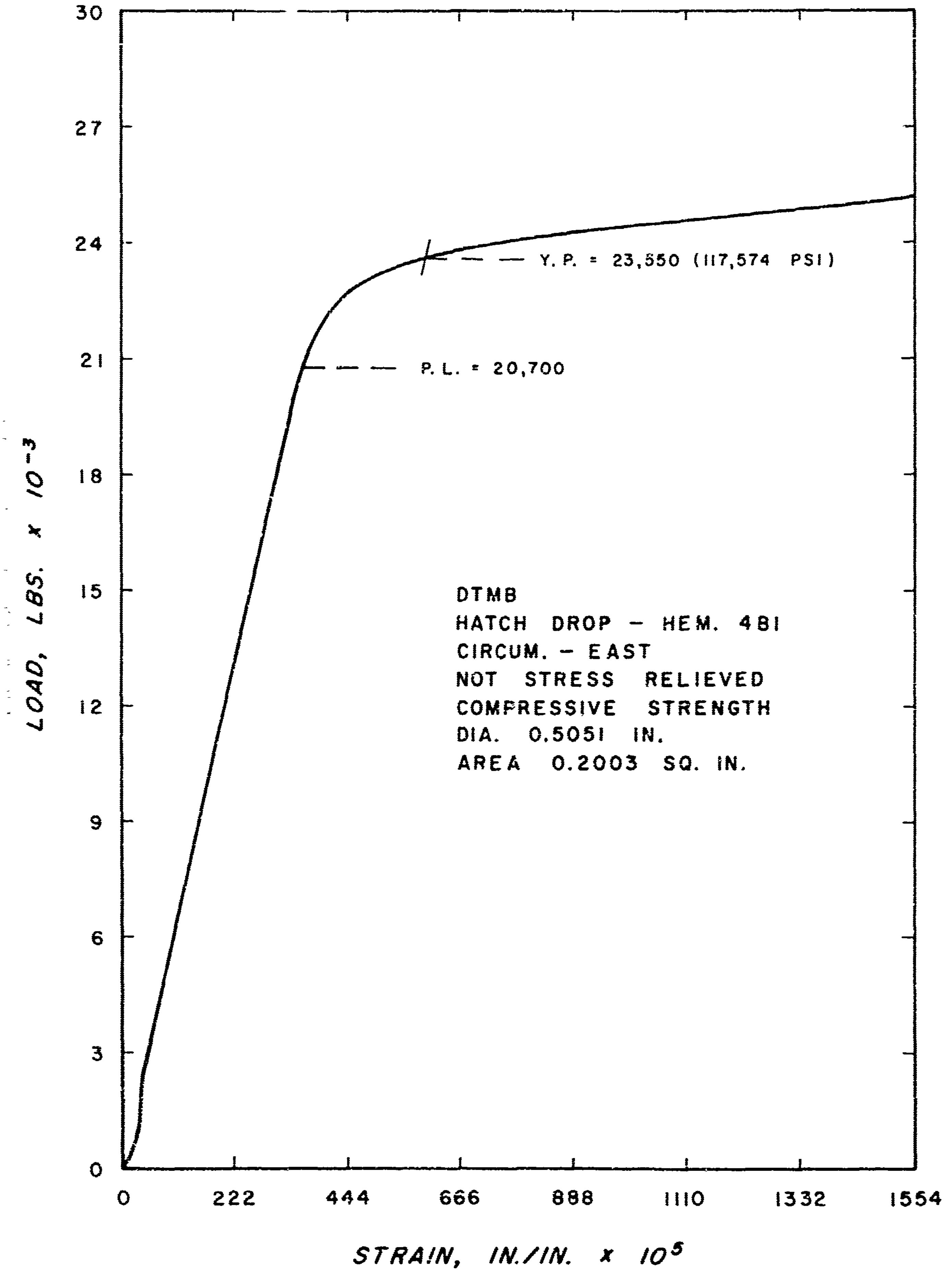


Fig. 10-11 Load Deflection Curve

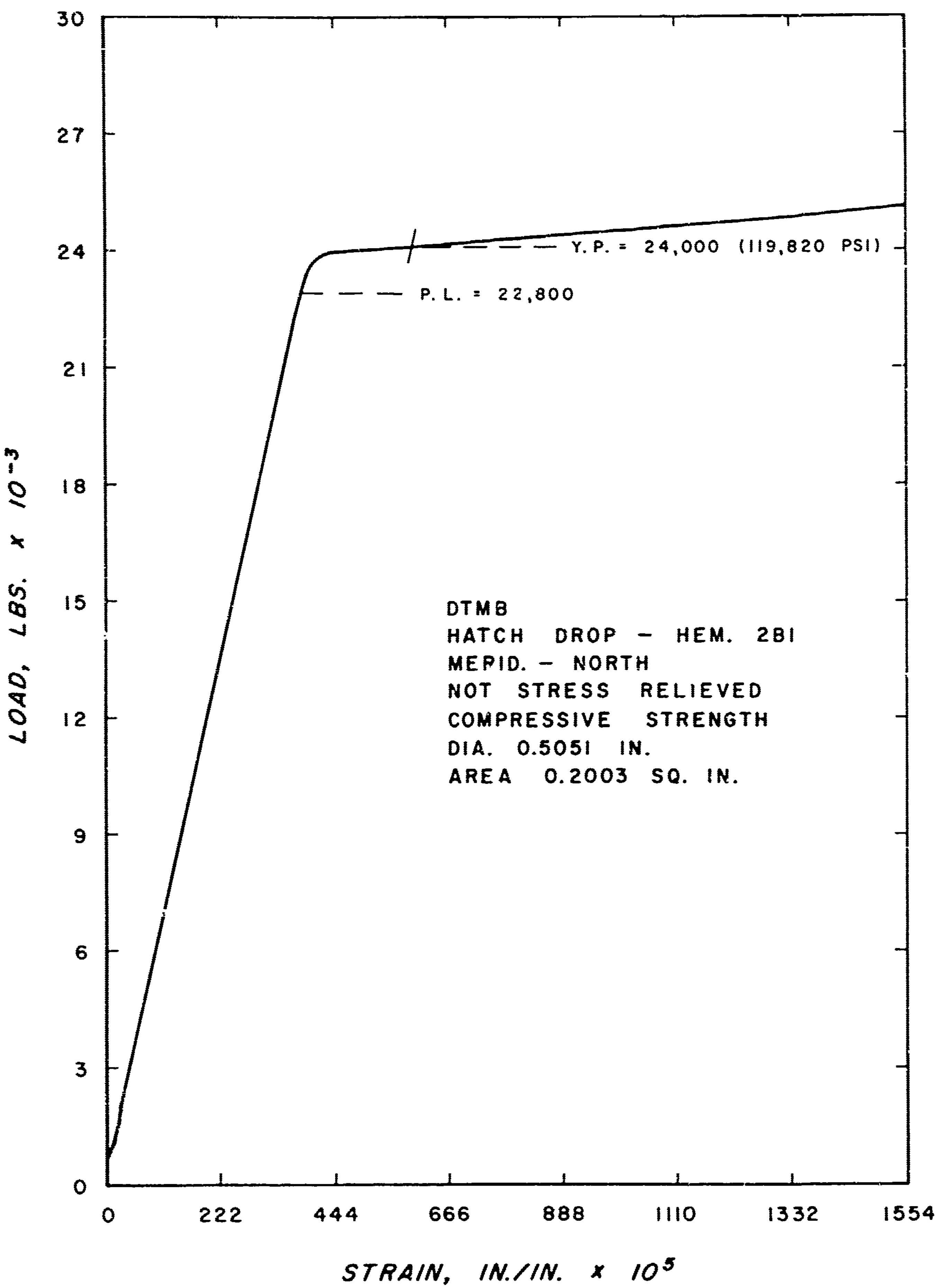


Fig. 10-12 Load Deflection Curve

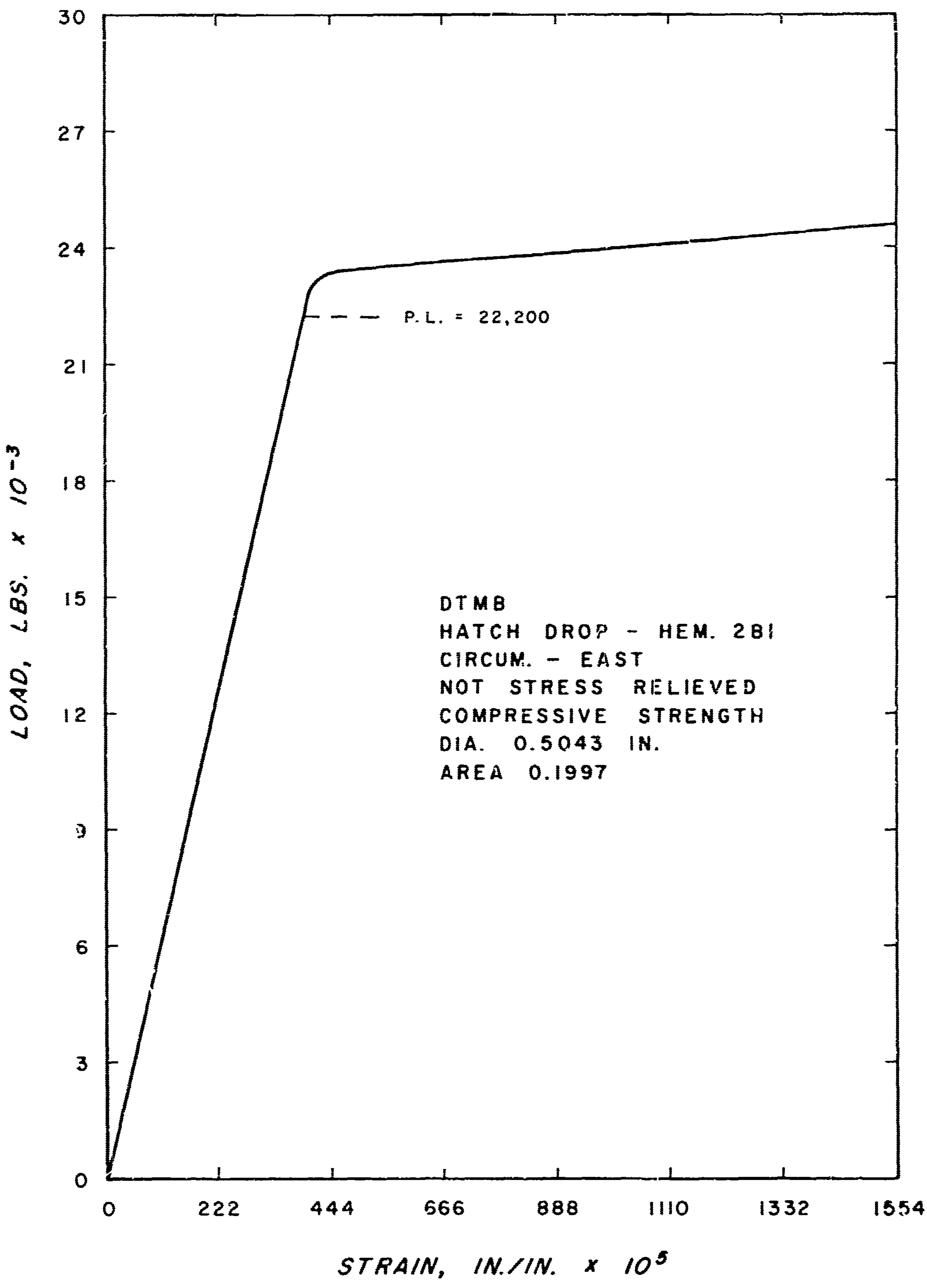


Fig. 10-13 Load Deflection Curve

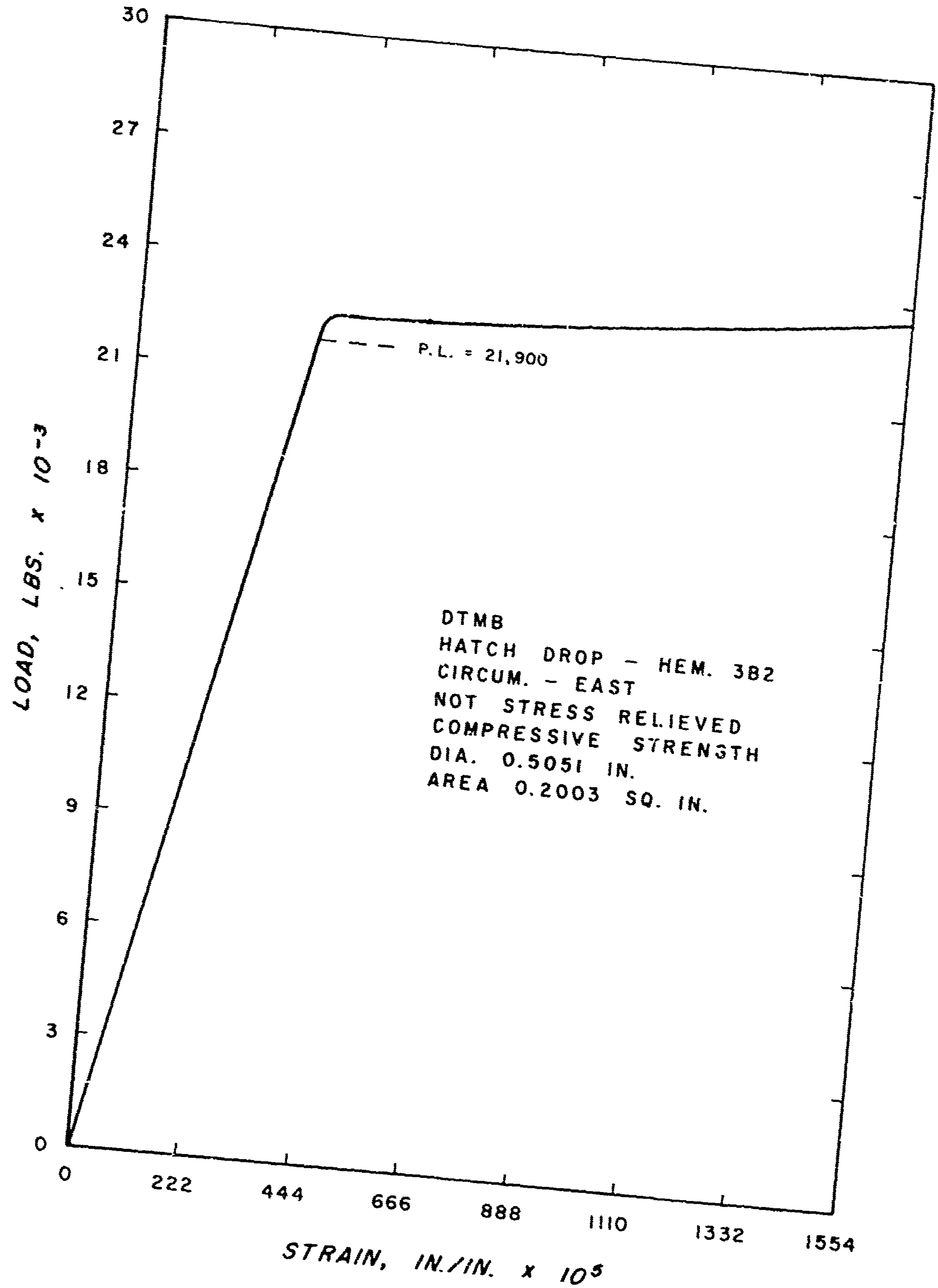


Fig. 10-14 Load Deflection Curve

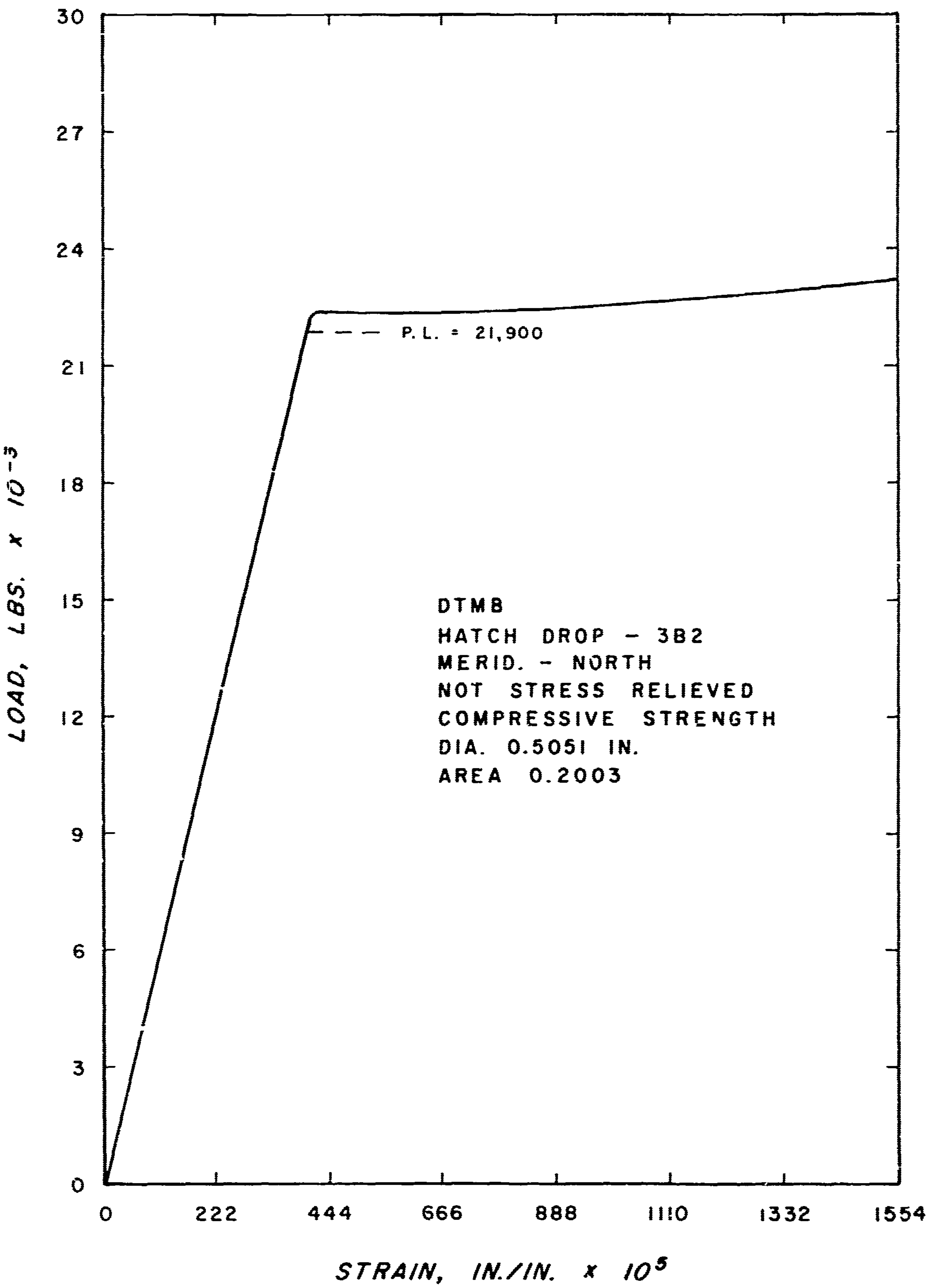


Fig. 10-15 Load Deflection Curve

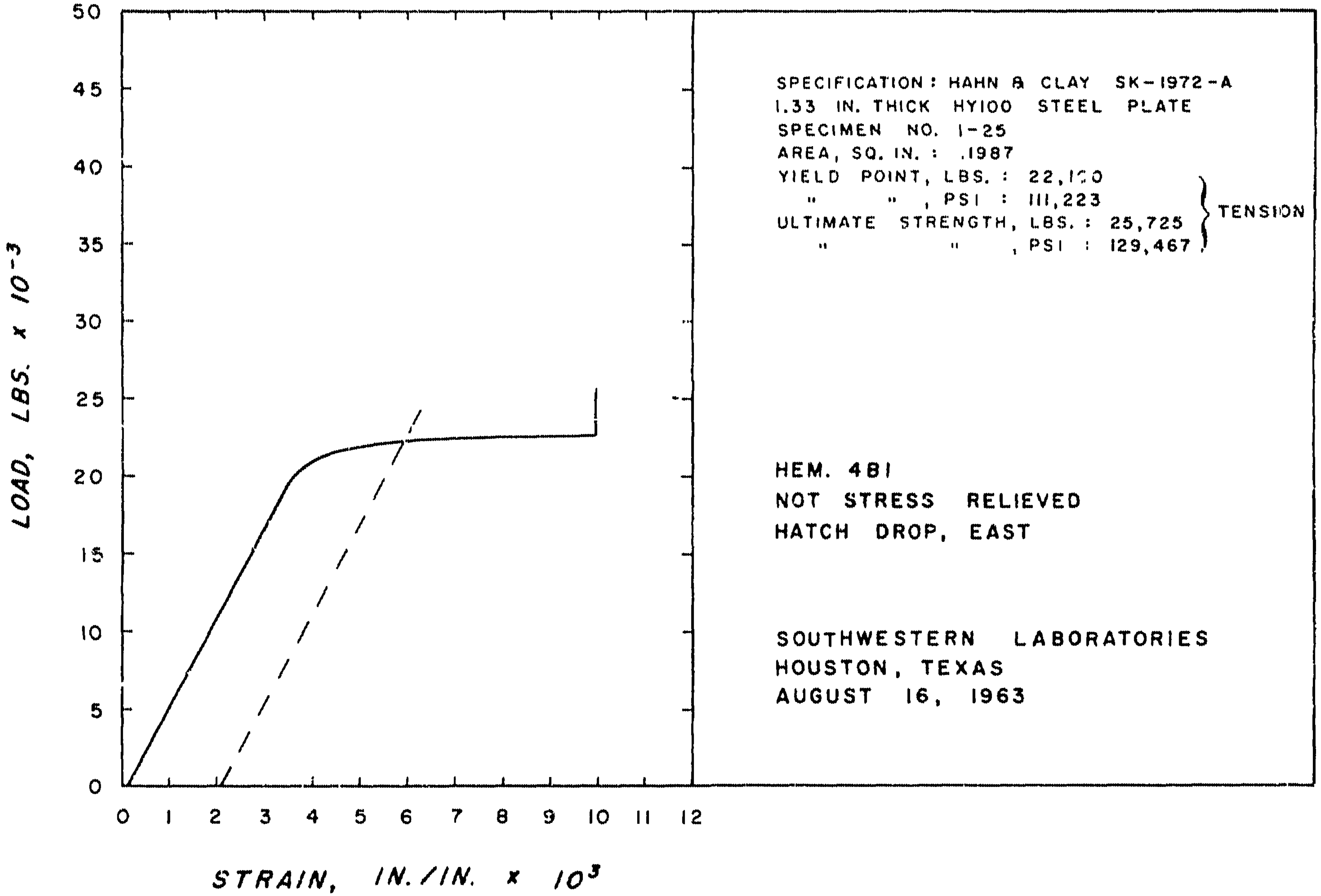


Fig. 10-16 Load Deflection Curve

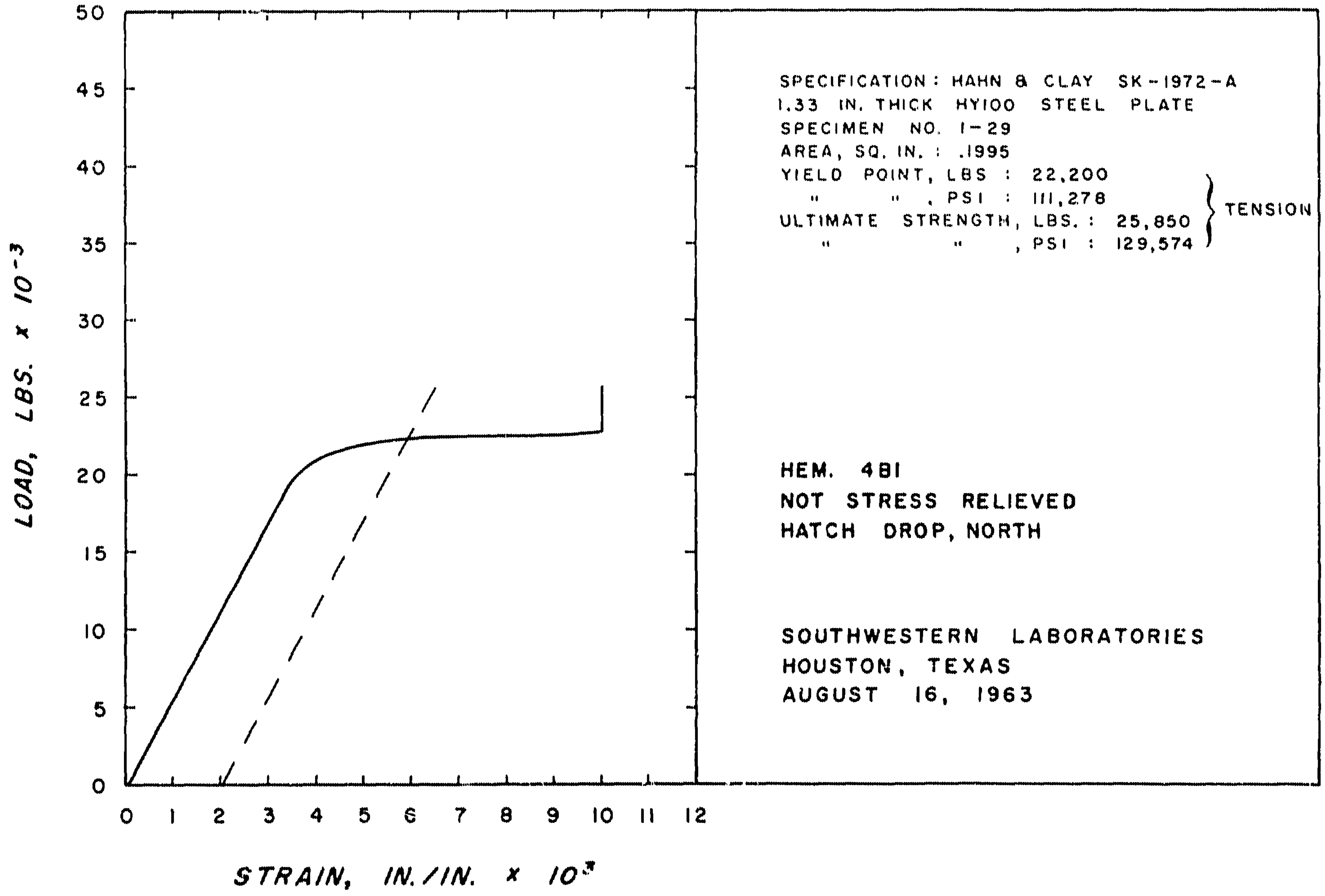
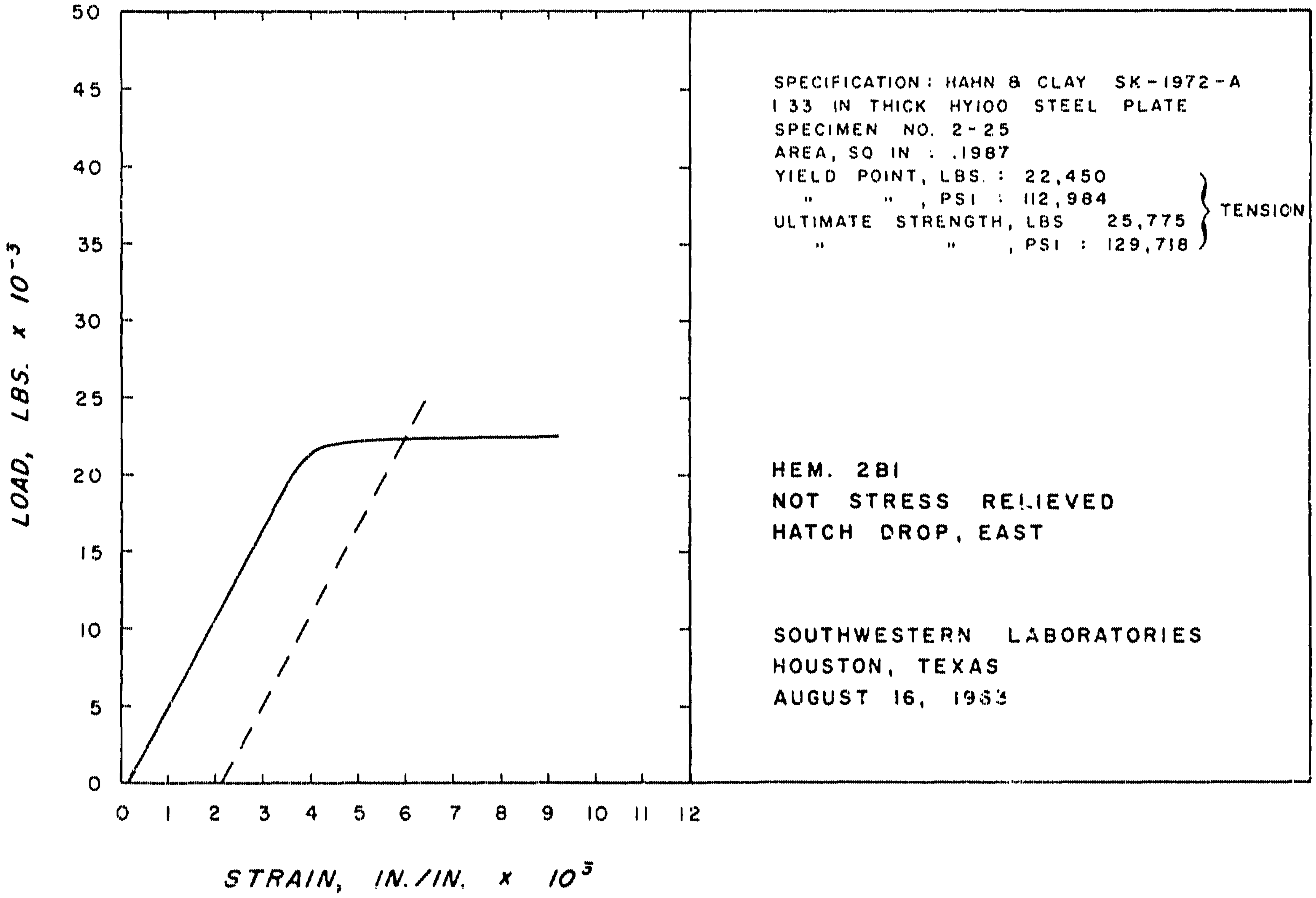


Fig. 10-17 Load Deflection Curve



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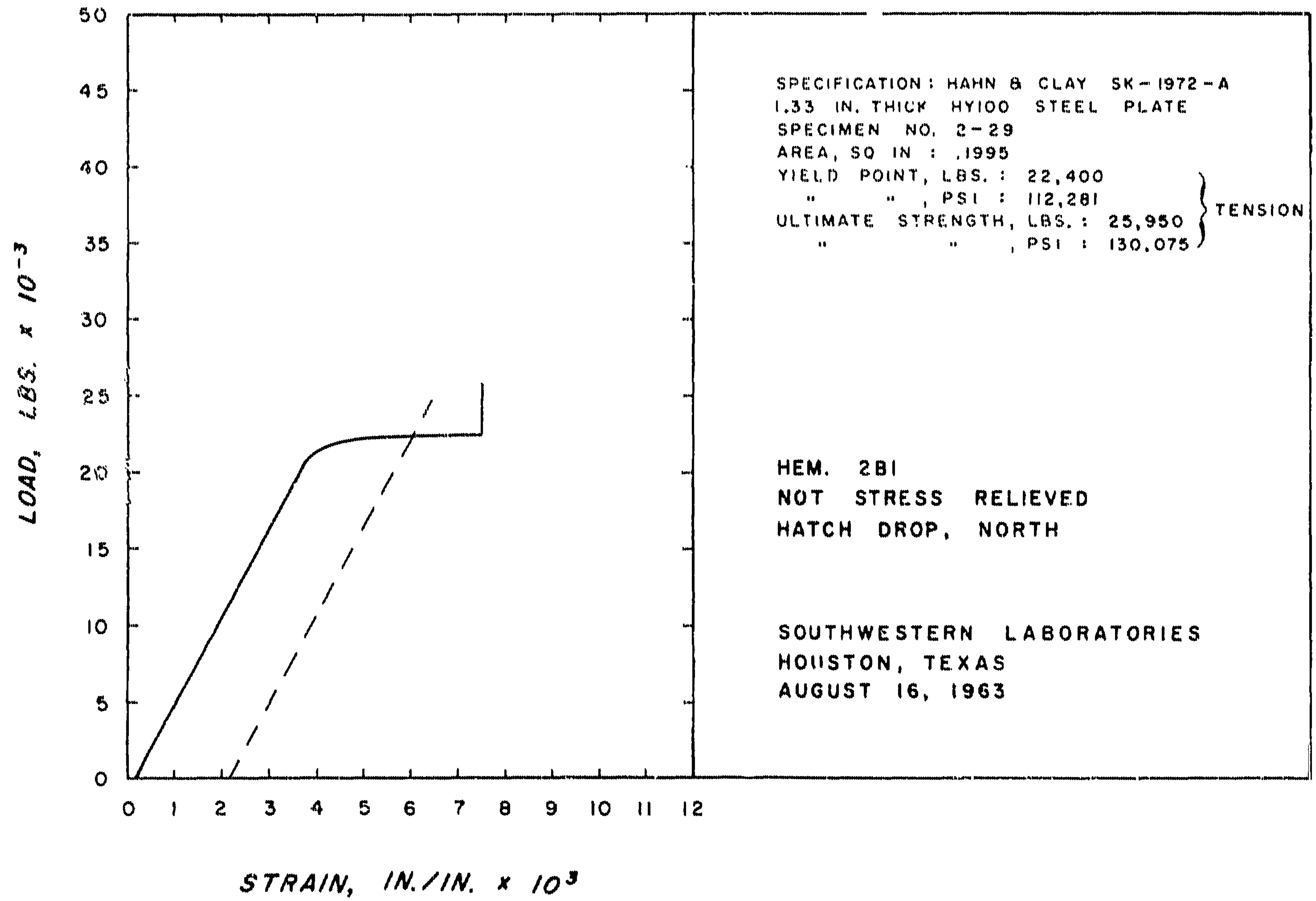


Fig. 10-19 Load Deflection Curve

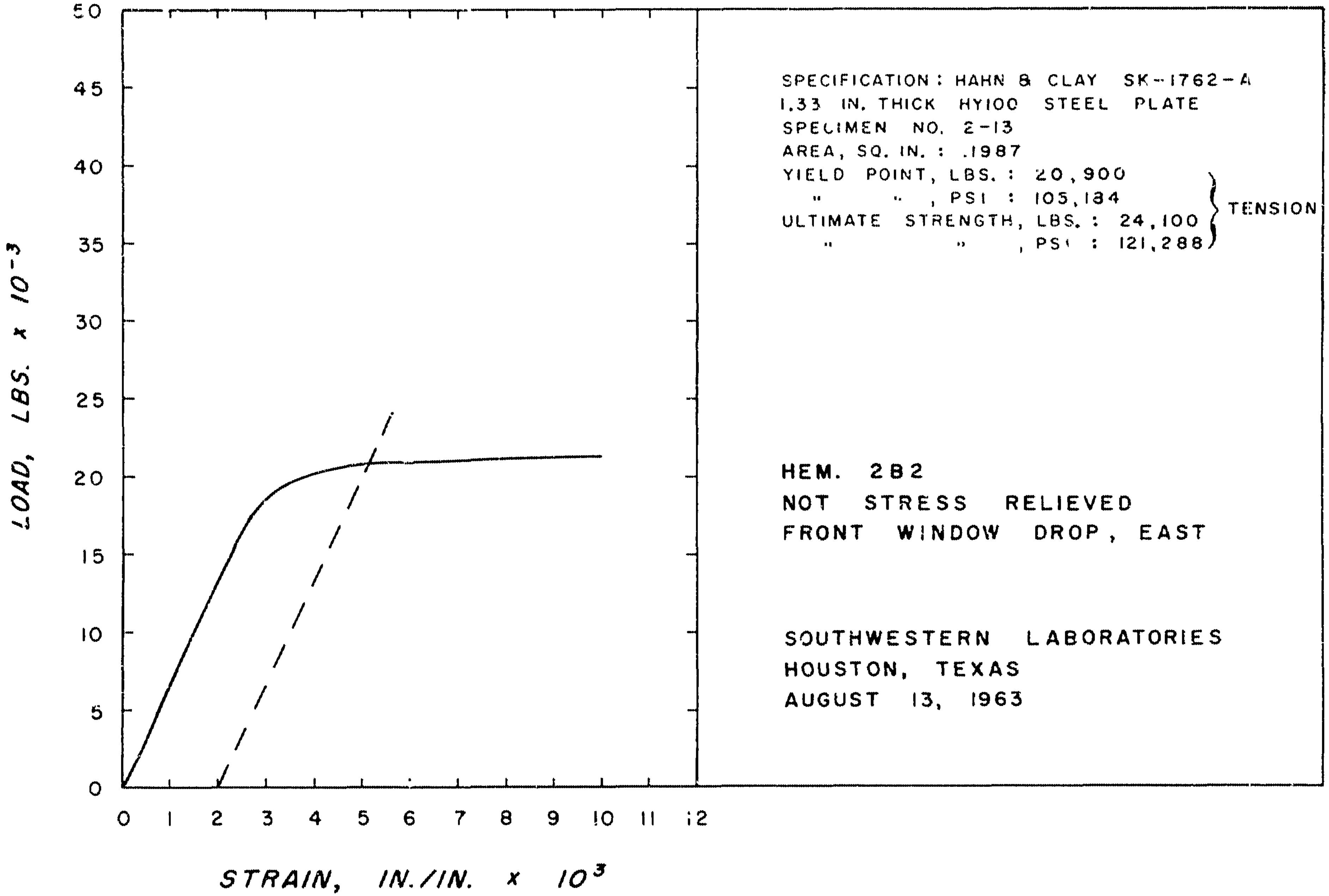


Fig. 10-20 Load Deflection Curve

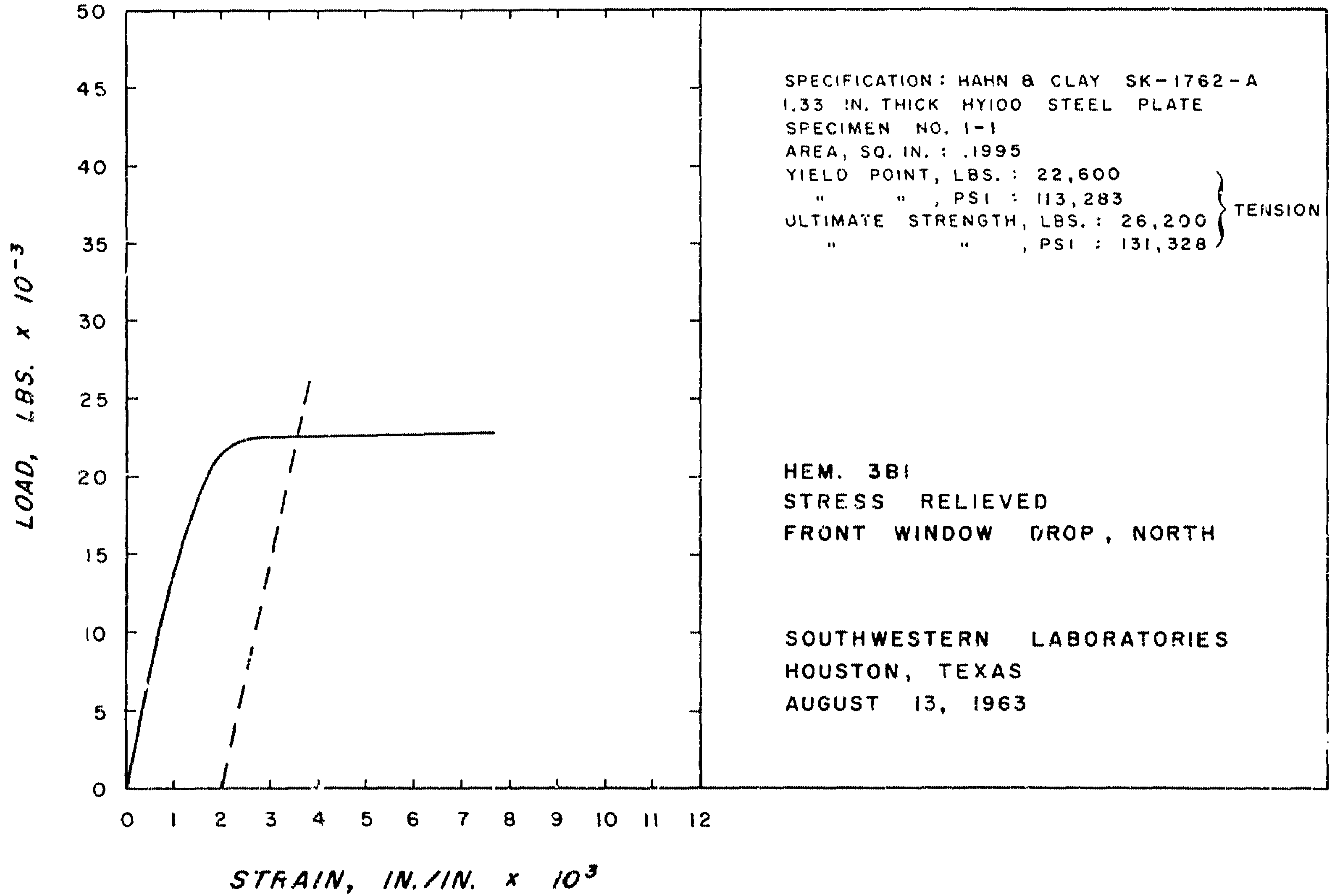
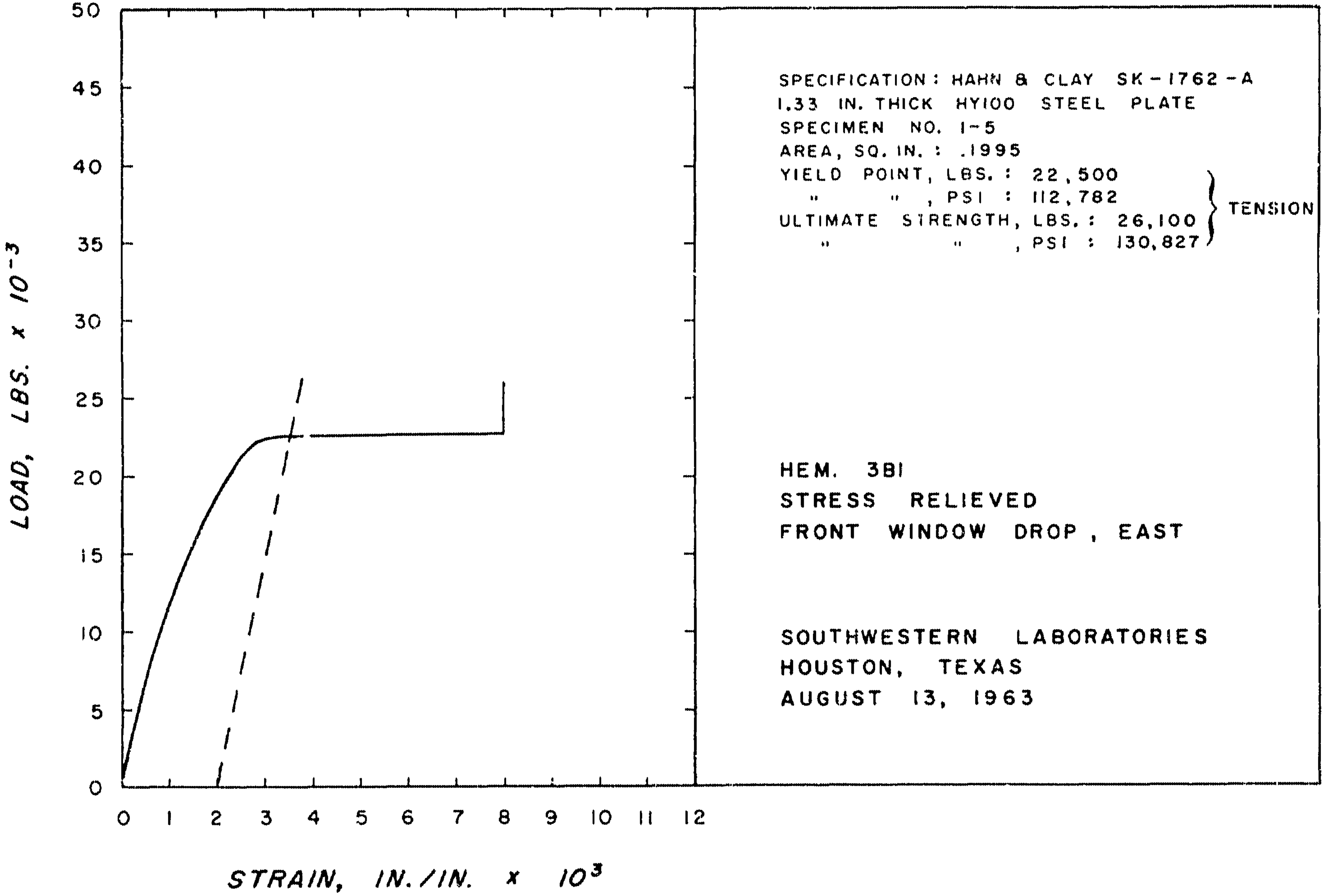


Fig. 10-21 Load Deflection Curve



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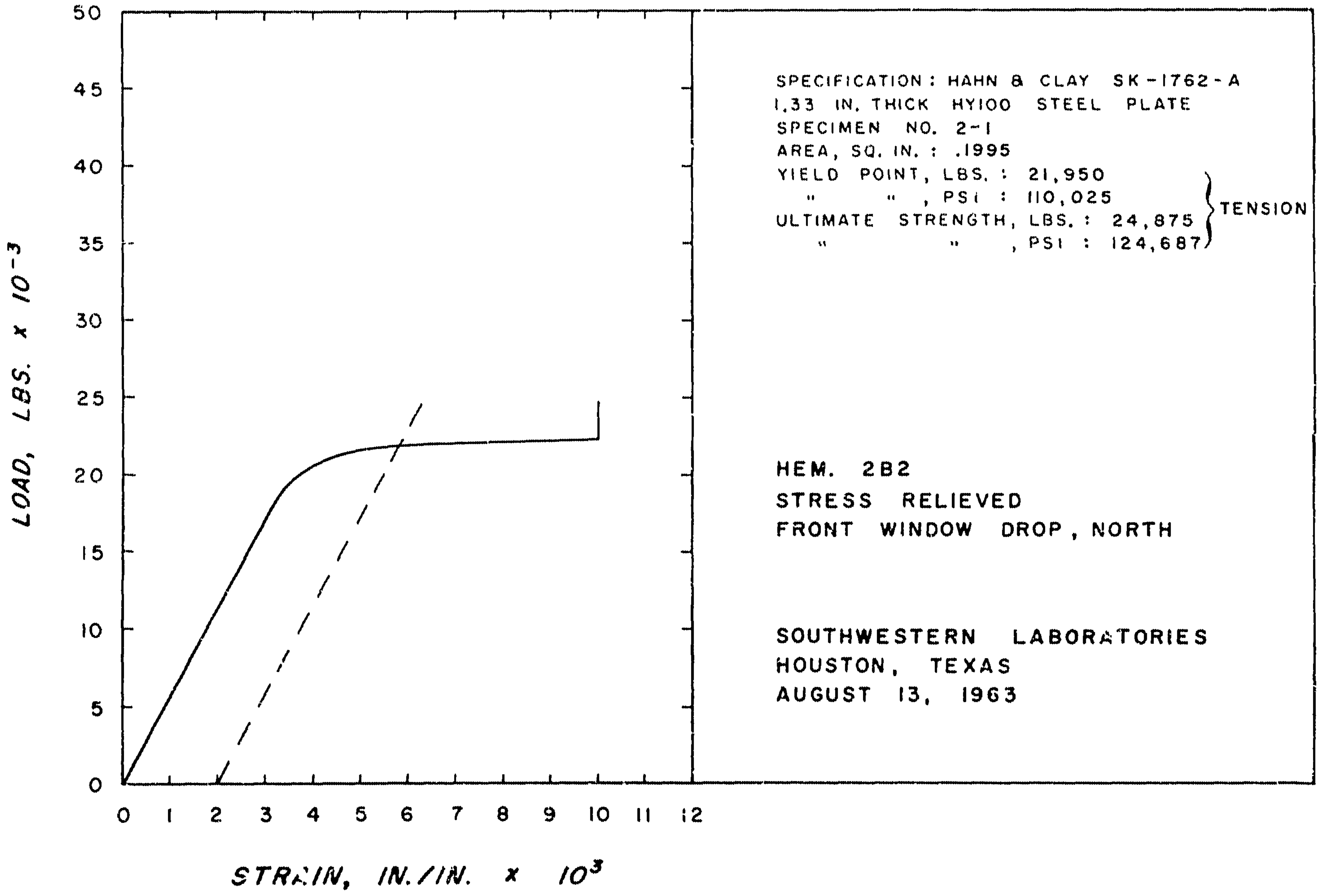

Fig. 10-23 Load Deflection Curve

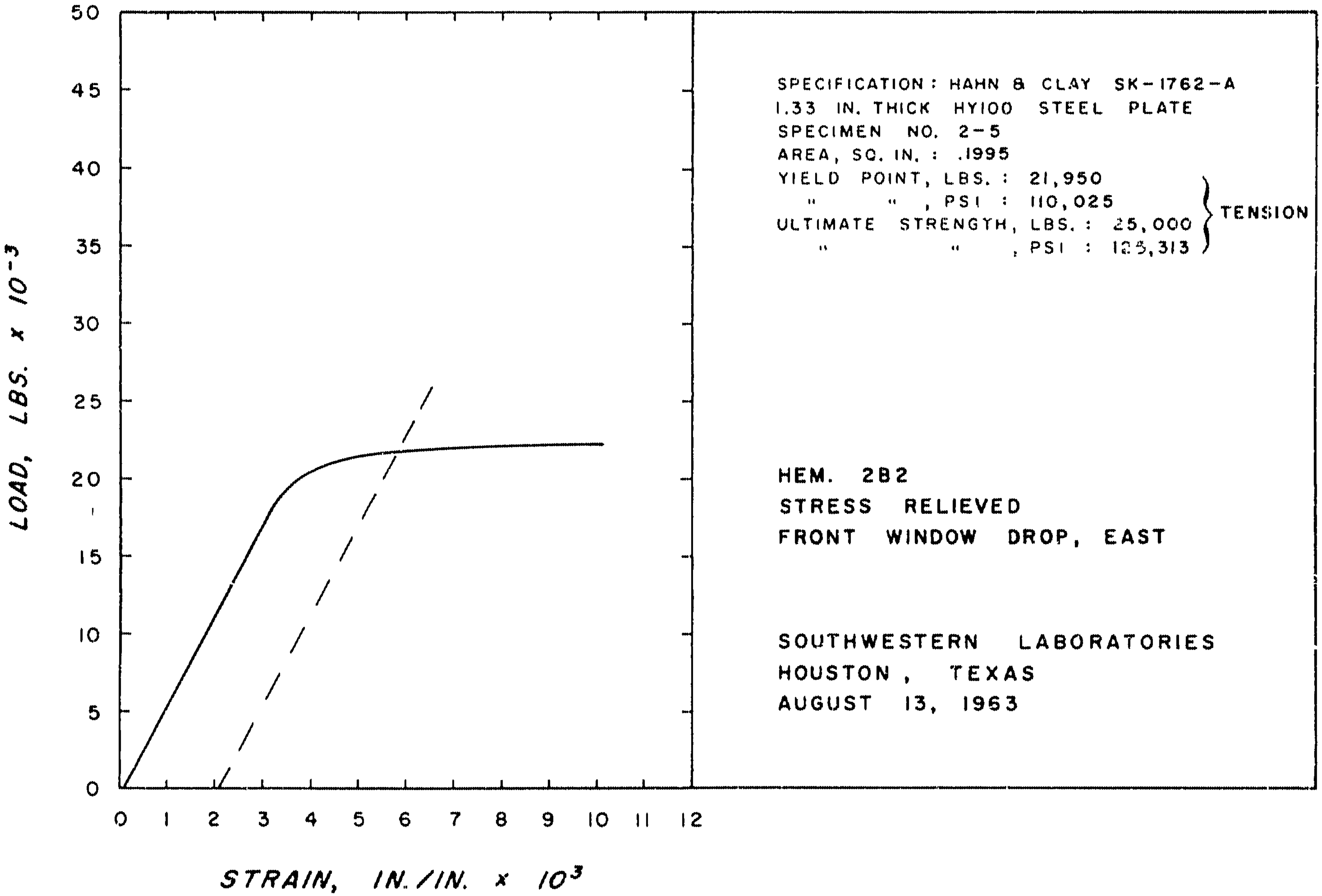

Fig. 10-24 Load Deflection Curve

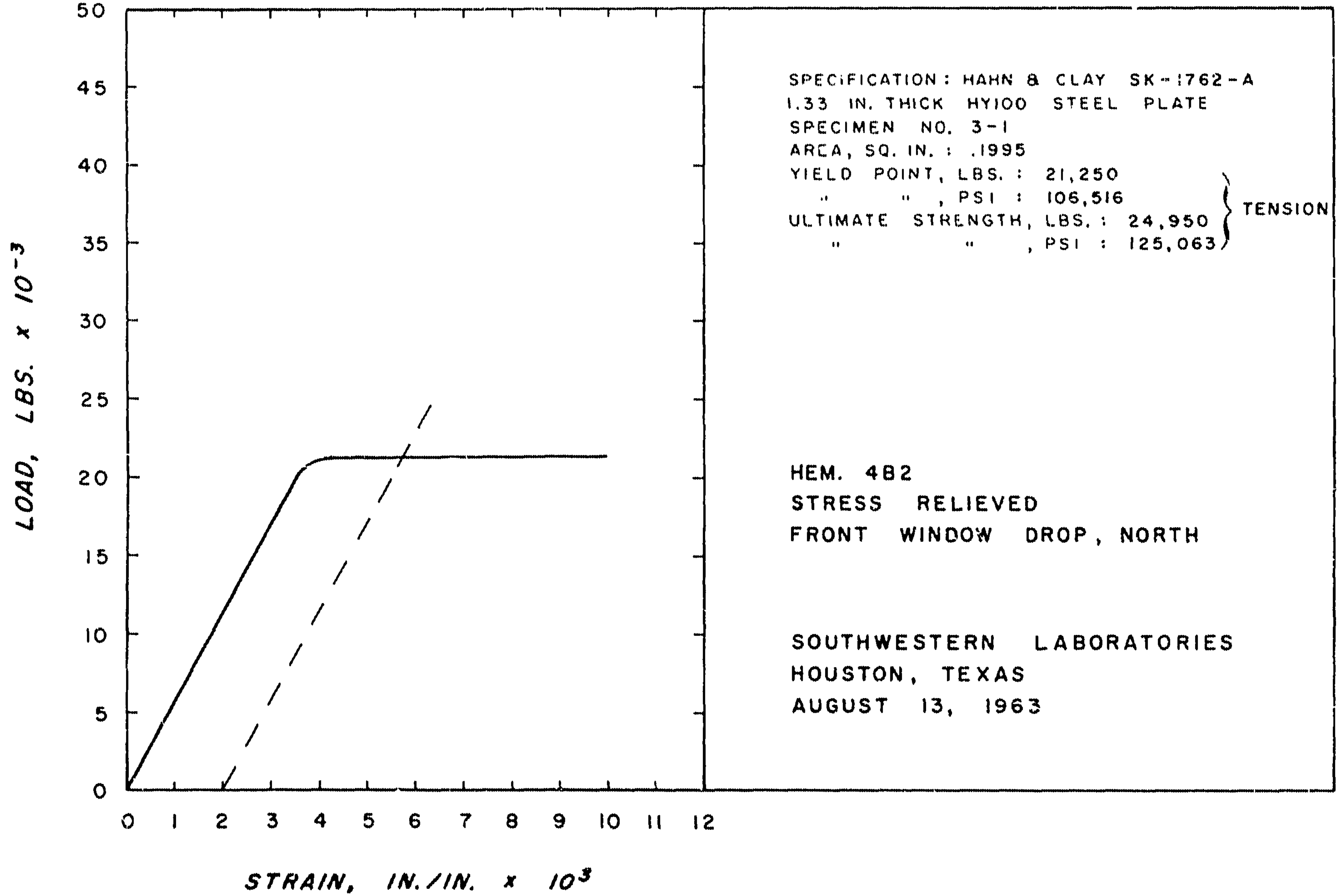

Fig. 10-25 Load Deflection Curve

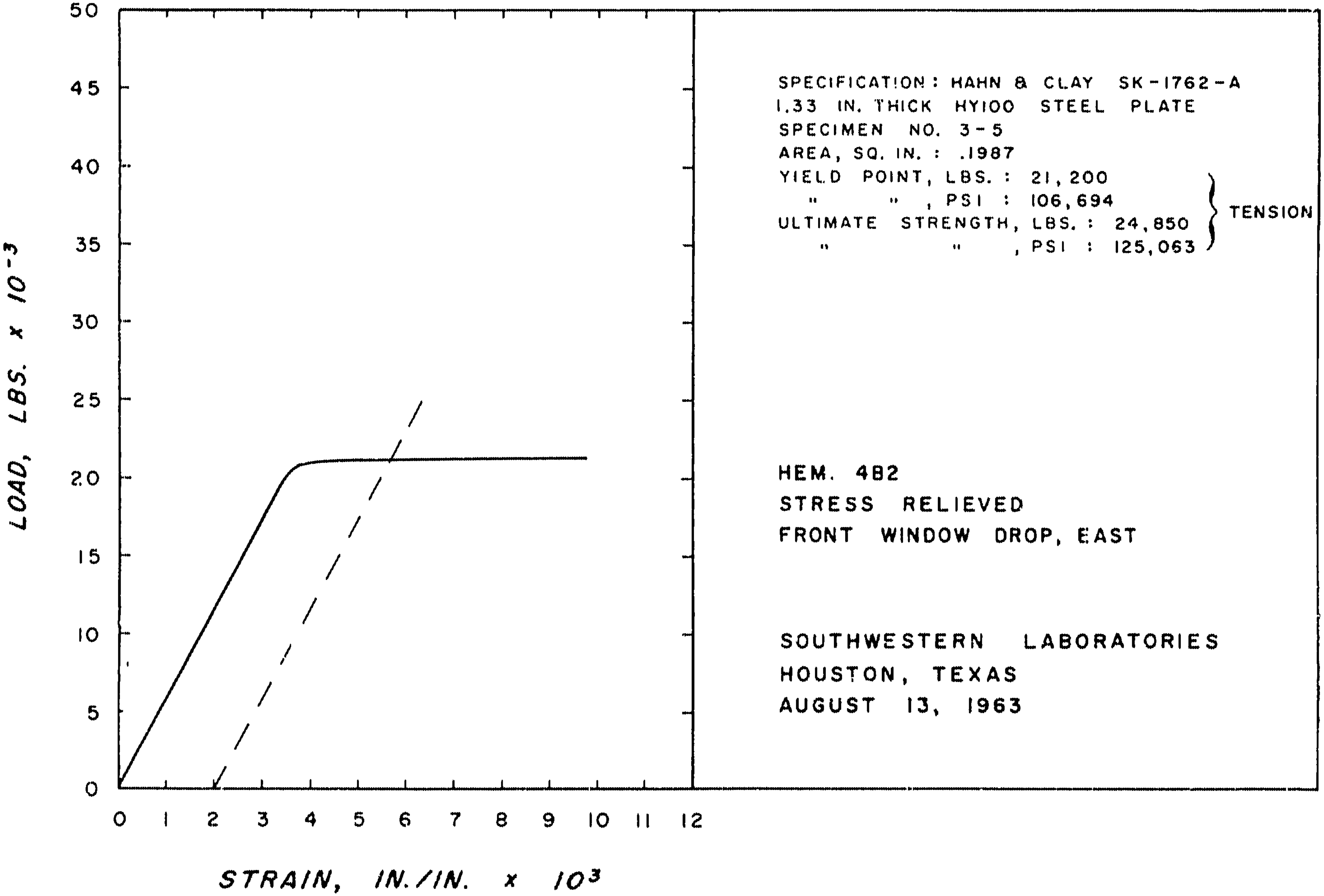

Fig. 10-26 Load Deflection Curve

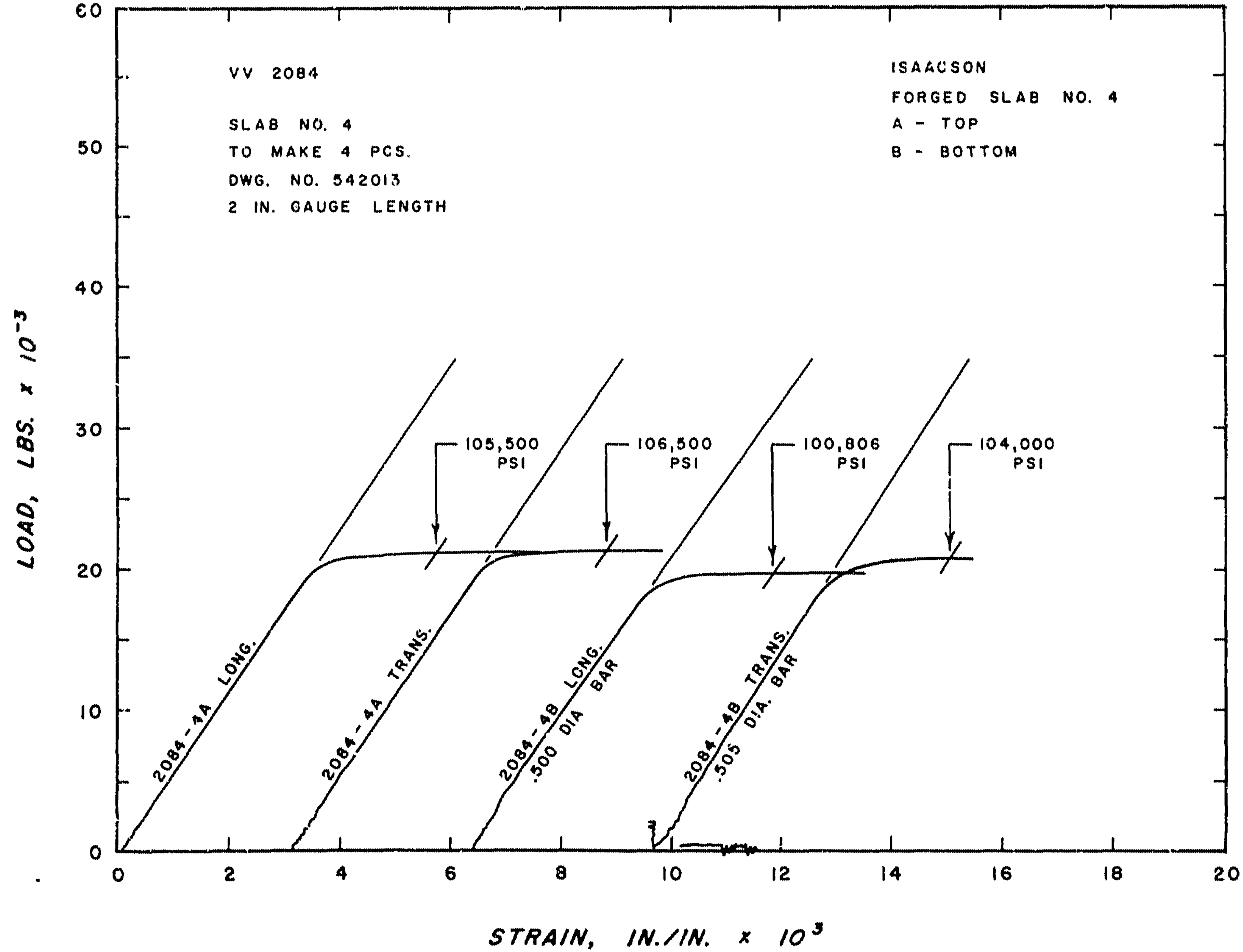

Fig. 10-27 Load Deflection Curve

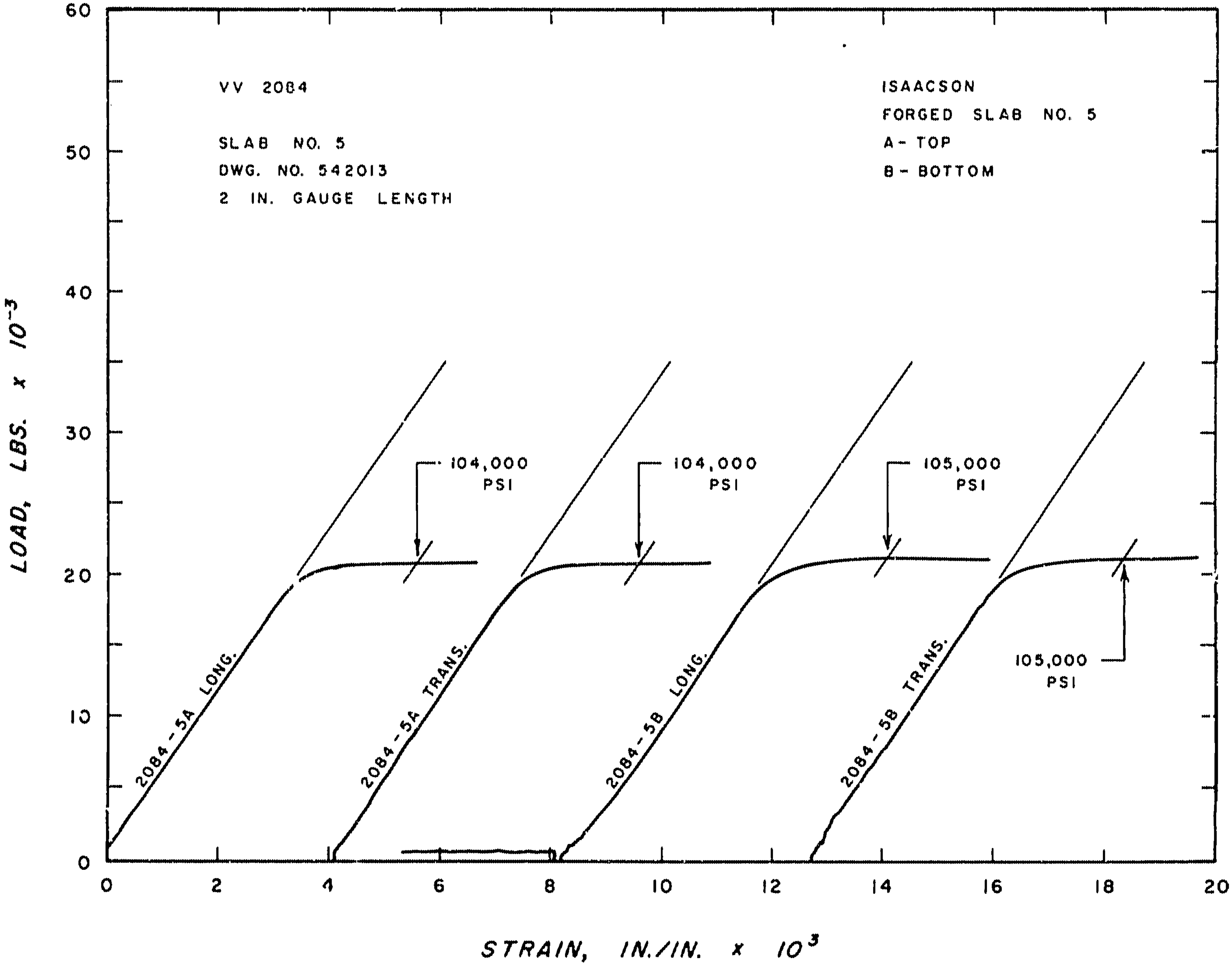

Fig. 10-28 Load Deflection Curve

STRESS, PSI x 10^{-3}

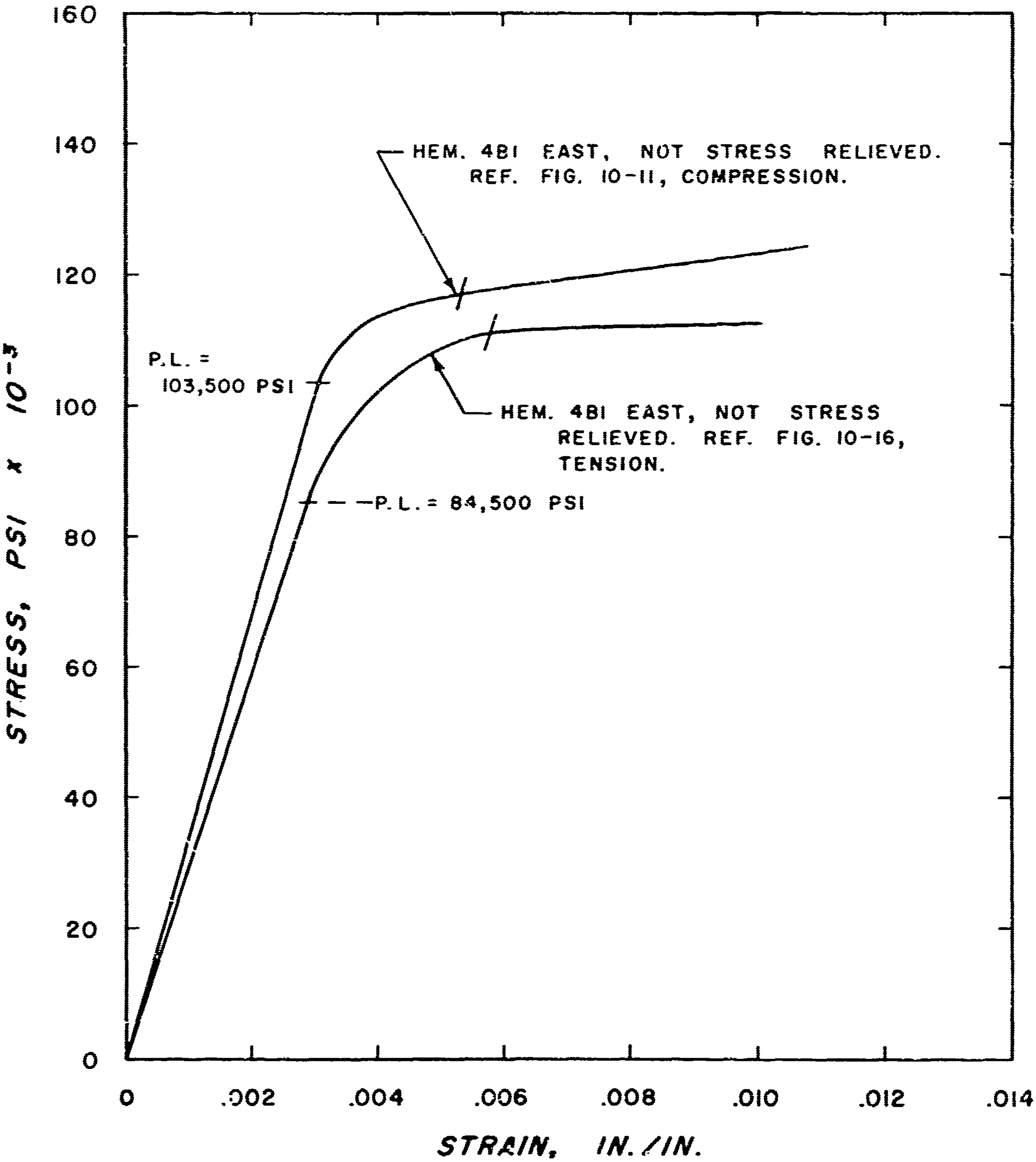

Fig. 11 Comparison of Compression and Tensile Properties

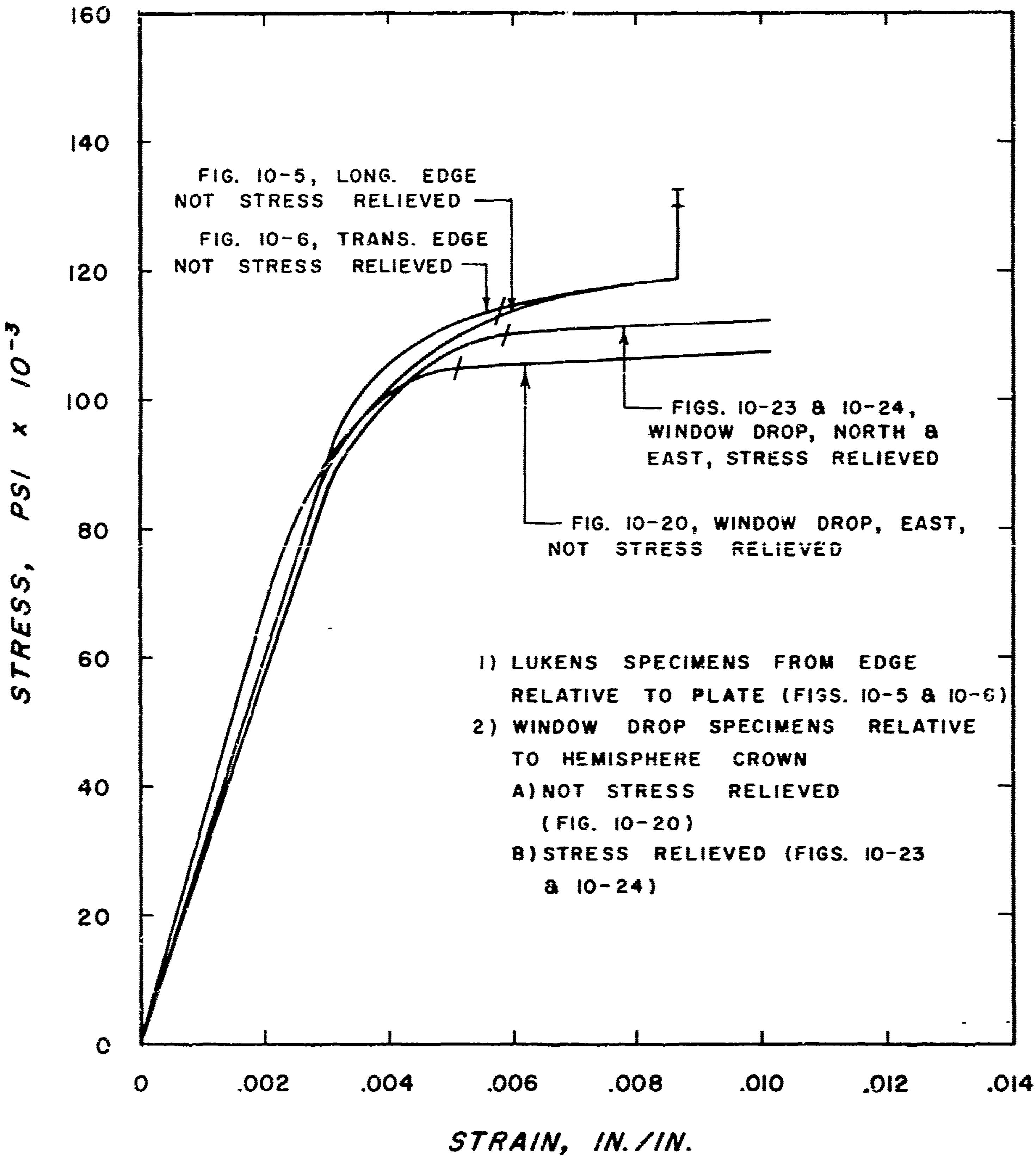

Fig. 12 Comparison of Tensile Data for Hemisphere 2B2

General and Specific References

1) McKay Co. Certificate of Electrode Performance, Jan. 8, 1964

2) Sheffield Div. Armco Certificate of Alloy Steel Plate, Nov. 9, 1962.

3) Sheffield Ltr. to L.F. Megow, Feb. 22, 1963.

4) Southwestern Laboratories weld qualification certificates to Hahn & Clay of 11/21/62, 11/26/62, 12/1/62, 12/6/62, 12/7/62, and 6/20/63.

5) Cook Heat Treating Co. Certification to Hahn & Clay, #11568 of 11/19/62.

6) Lukens Test Certificate for Melt B0091 of Mar. 14, 1963.

7) Southwestern Lab. Tests on Steel Drillings from Forgings 10/3/63.

8) " " " " " " " Hemispheres 10/3/63.

9) "Procedure & Welder Qualification Results for ALVIN Project Pressure Hulls", Hahn & Clay, 4/5/63.

10) Southwestern Lab. Certificates Job 65253, Hull 1, 8/10/63,Spec.1-17.

11) " " " " " " " " Spec.1-21.

12) Letter from NYNS to Chief BuShips (210L) (3) 29 Mar. 1963, Subject, "HY 100, Weldability of 2" thick rolled plate".

13) "Charpy V-notch properties of Rich Analysis HY 80 plate material re-heat treated to a Y.S. of 100,000/120,000 psi", by F.Ginsberg and I.A. Schwartz, MATLAB, NYNS, 14 Aug. 1959.

14) "Fracture Analysis Diagram Procedures for the Fracture Safe Engineering Design of Steel Structures", by W.S. Pellini and P.P. Puzak, NRL Report 5920, Mar. 15, 1963.

15) "Explosion Bulge Test Performance of Quenched and Tempered Steel Weldments", by P.P. Puzak, NRL Report 4919, May 17, 1957.

General and Specific References (continued)

16)	Southwestern	Lab.	Certification	Lab.	No.	130601,	Aug.	16,	1963
	"	"	"	"	"	130519,	"	13,	"
	"	"	"	"	"	130523,	"	10,	"
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	"	"	"	"	"	125983,	Nov.	26,	1962
	"	"	"	"	"	130596,	Aug.	16,	1963
	"	"	"	"	"	130600,	"	14,	"
	"	"	"	"	"	130599,	"	14,	"
	"	"	"	"	"	130595,	"	16,	"

17) Hahn & Clay Quality Assurance Report for Hull No. 3, Oct. 14, 1963.

18) Hahn & Clay Quality Assurance Report for Hull No. 1, Sept.26, 1963.

19) WHOI Specifications for 6,000' Submarine, May 1962.

20) Special Provisions Schedule B of WHOI-GMI Contract compiled by BuShips, USN.

21) NAVSHIPS 250-637-3

22) MIL-E-22200/B Ships

23) MIL-S-16316F Ships

24) MIL-S-23009 Ships

25) "The Practicability of Fabricating a Full-Scale Submarine Hull Section from Steel with a Minimum Y.S. of 100,000 psi". Edited by S.R. Heller, PNW Project S-R-007-01-01, Feb. 1961.

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3. Mechanical Engineering

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